STAR Forward Upgrade

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Outline

Why Forward Upgrade? - Physics Motivations

- $p^{\uparrow}$ + A physics
- $p^{\uparrow} + p^{\uparrow}$ physics

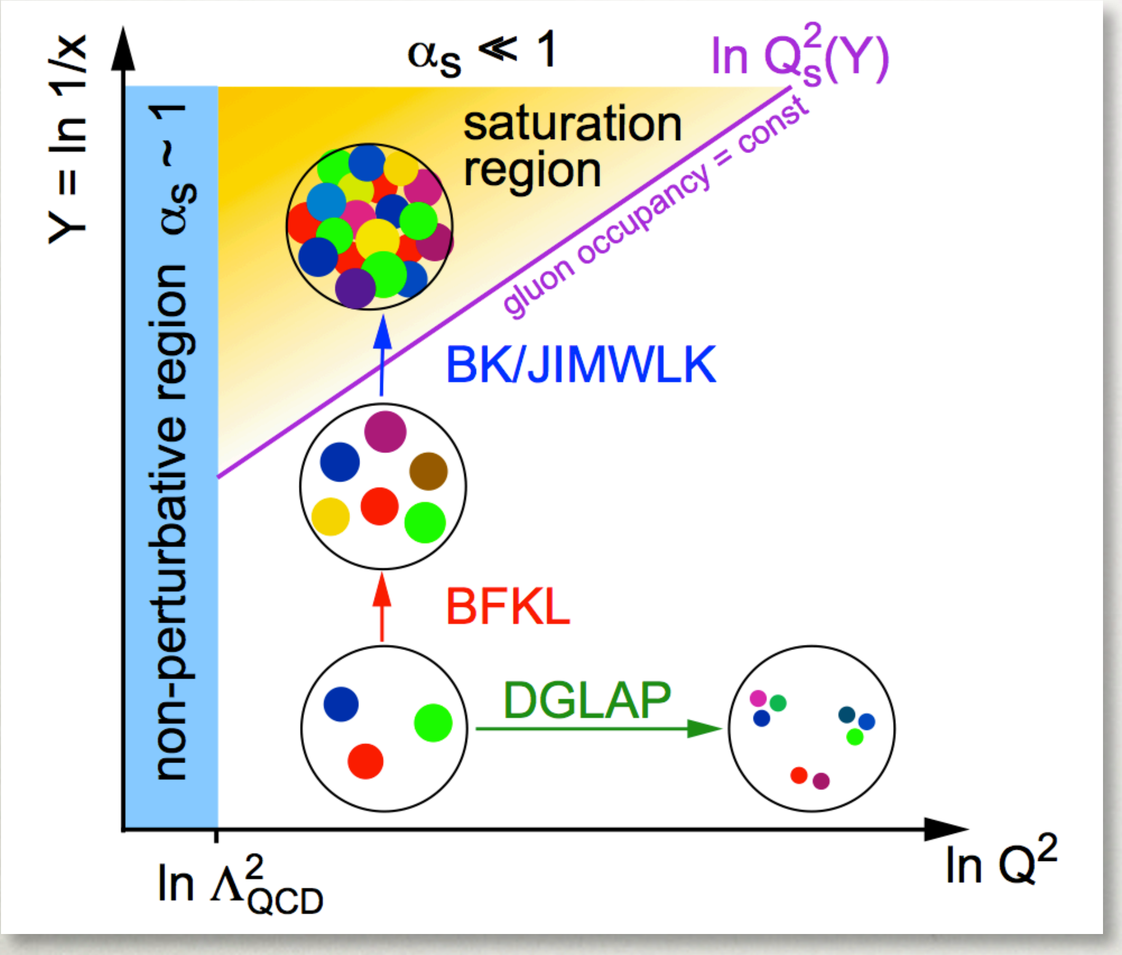
Near-to-Mid Term Upgrade Paths / Possibilities

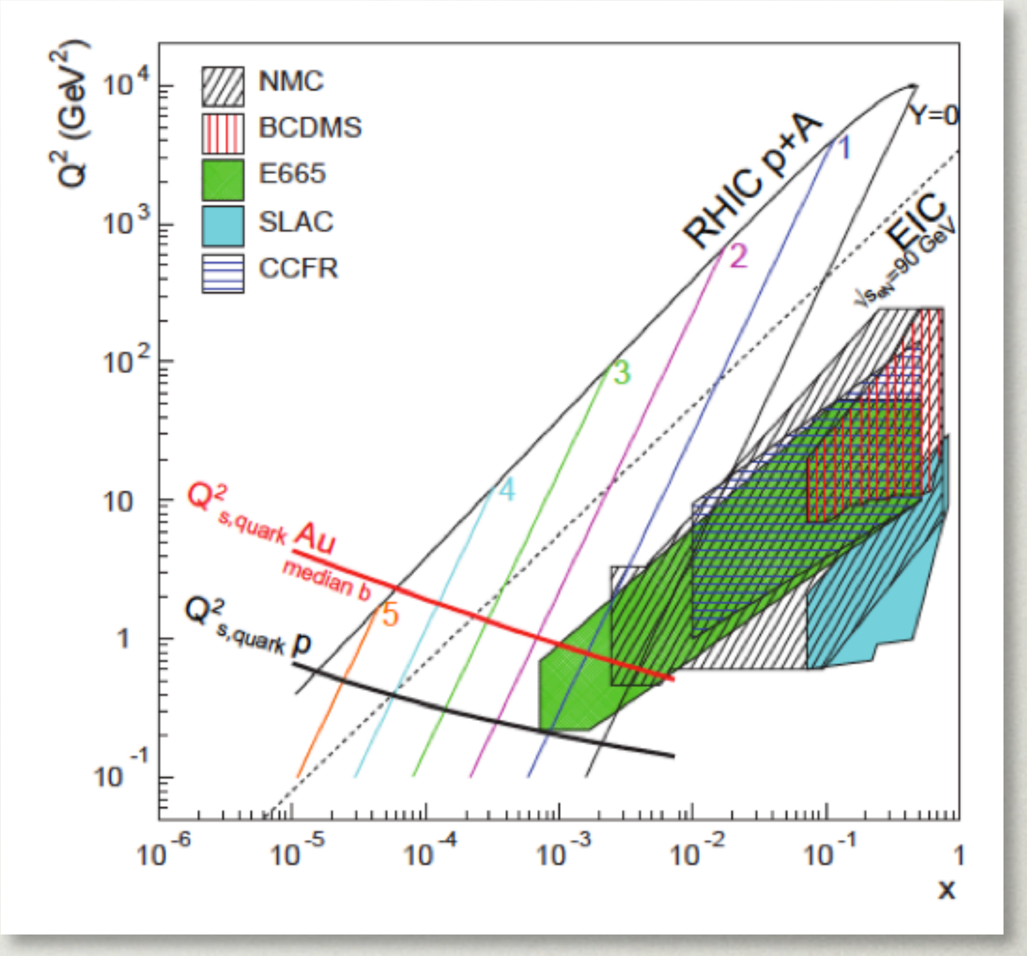
- *Forward Calorimeters:*
  1. Forward Calorimeter System (FCS)
  2. FMS + Forward Hadron Calorimeter (FHC)
- FMS Preshower Detector
- Displaced Vertex Finder for Λ-hyperon
- *Forward Tracking:*
  1. Very Forward GEM Tracker (VFGT)
  2. Forward Silicon Strip Tracker
- Roman Pot Phase II

Summary

$p^{\uparrow}$+A Forward Physics

For p+A collisions, RHIC has the unique capability to polarize the proton beam, and vary both the collision energy and the system size.





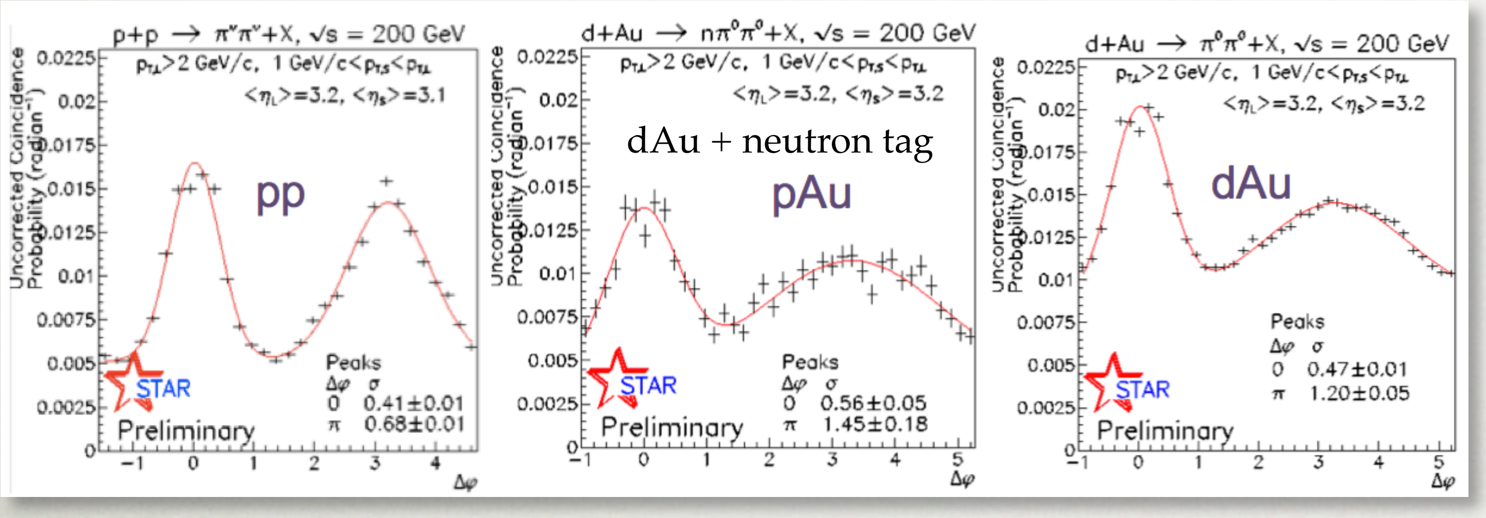
STAR can probe saturation / CGC physics and low-x gluon nPDF, including spin dependent observables.

Many of these channels require upgraded instrumentation in the forward region.

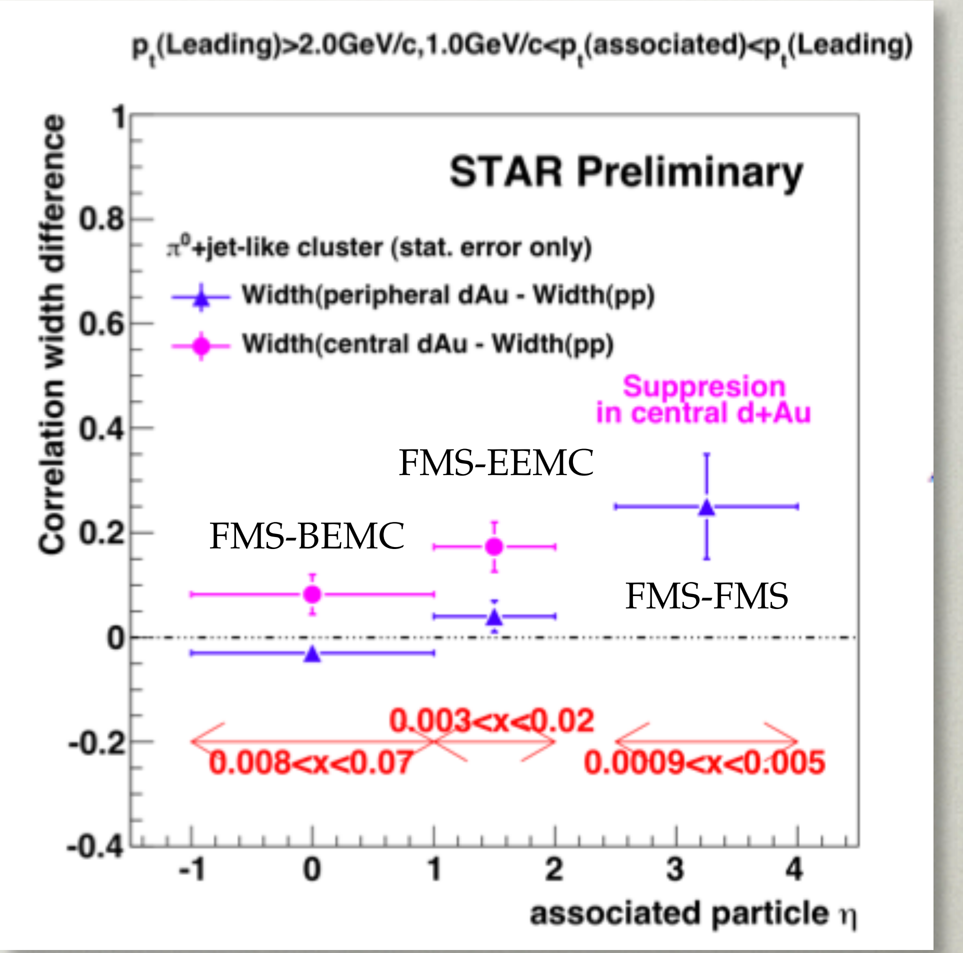
Forward Correlations

STAR has preliminary results on forward π^0 - π^0 correlation, which show away side peak broadening consistent with the expectations of CGC

Forward π^0 - Forward π^0 correlations



π^0 - Jet-like cluster correlations



pA collisions will suppress multiple parton interaction w.r.t dA, which may contribute to the observed broadening. (Strikman & Vogelsang, Phys. Rev. D 83, 034029 (2011))

Expand the forward correlation measurements:

Easy to measure: **h - h**, **π^0 - π^0**

Easy to interpret: **γ - h**, **γ - π^0**

Requires forward upgrade

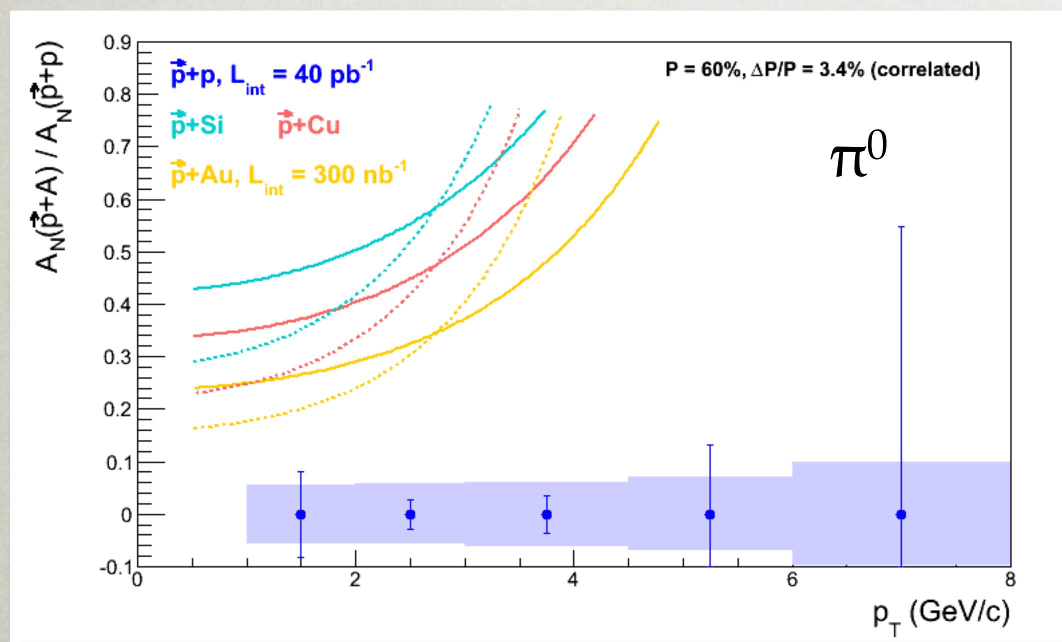
Spin Observables

RHIC can access spin dependent channels that probe the saturation scale, Q_S.

For low p_T forward inclusive hadrons, the ratio of $A_N(pp)$ and $A_N(pA)$ is expected to be sensitive to Q_S.

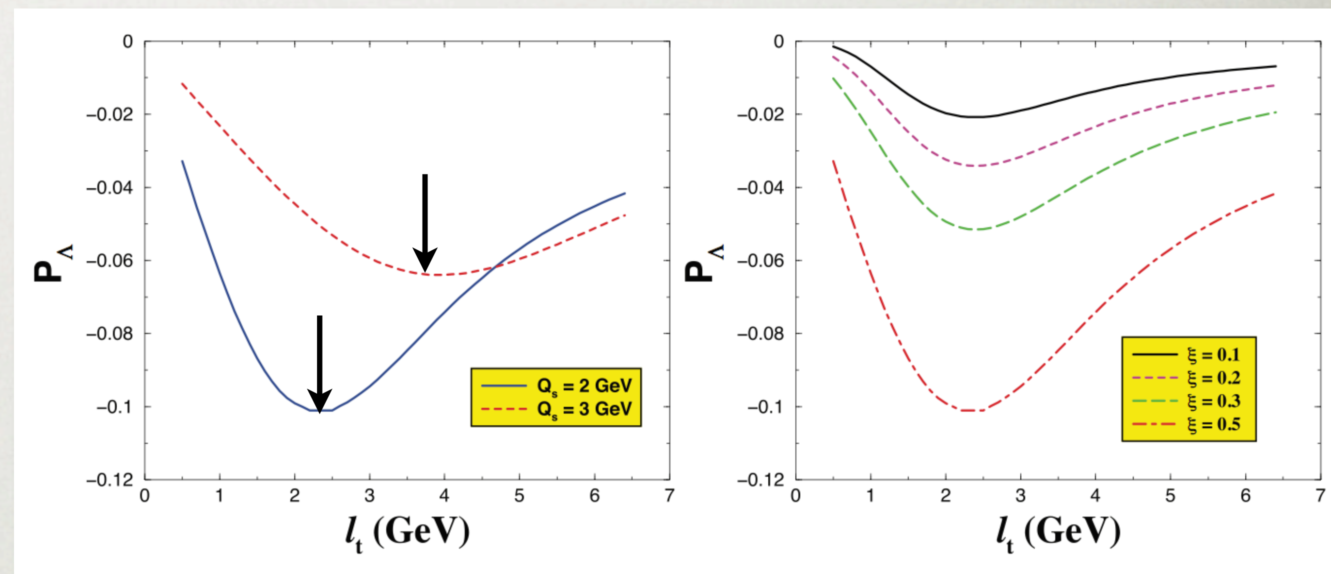
$$\left.\frac{A_N^{pA\to h}}{A_N^{pp\to h}}\right|_{P_{h\perp}^2 \ll Q_s^2} \approx \frac{Q_{sp}^2}{Q_{sA}^2} e^{\frac{P_{h\perp}^2 \delta^2}{Q_{sp}^4}}$$

Z. Kang, F. Yuan, Phys. Rev. D 84, 034019 (2011)



Curves: Solid: Q_s^p = 1 GeV; dashed: Q_s^p = 0.5 GeV

The transverse polarization of **forward Λ**'s is expected to be proportional to the derivative of the quark-nucleus cross section w.r.t. p_T, which should peak around Q_S.



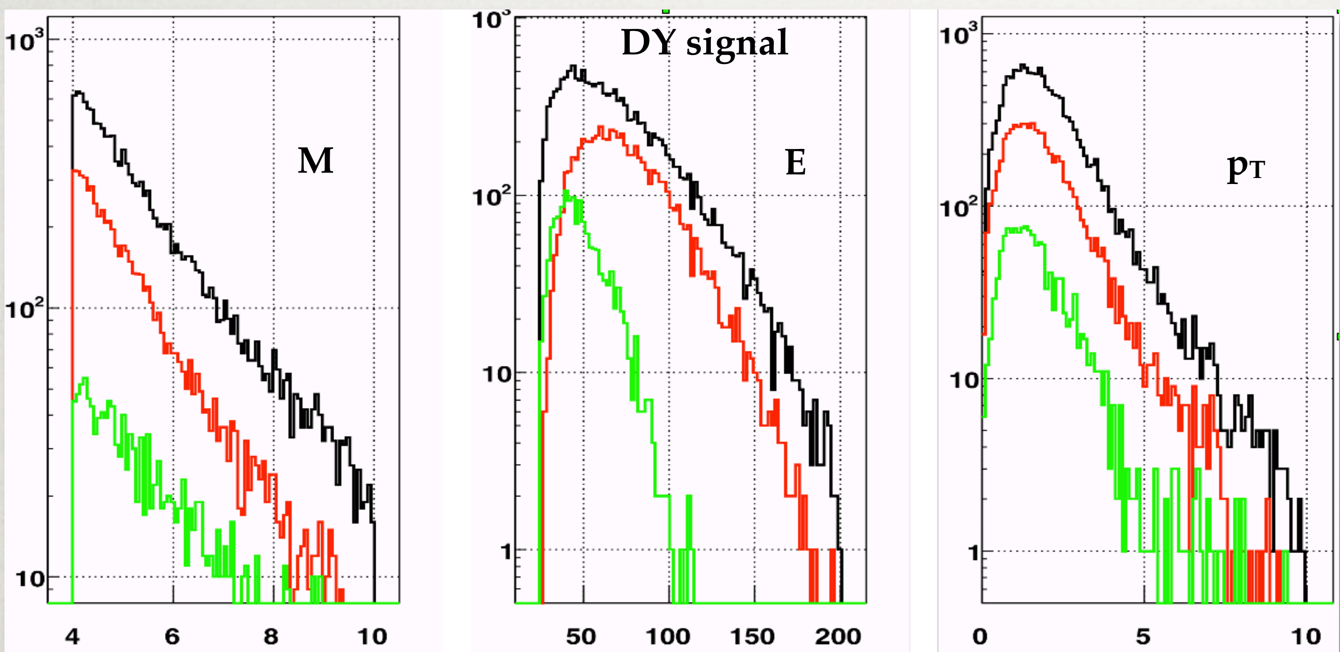
D. Boer, A. Dumitru, Phys.Lett. B556 (2003) 33-40

Λ requires either neutron ID, or charged track with displaced vertex measurement.

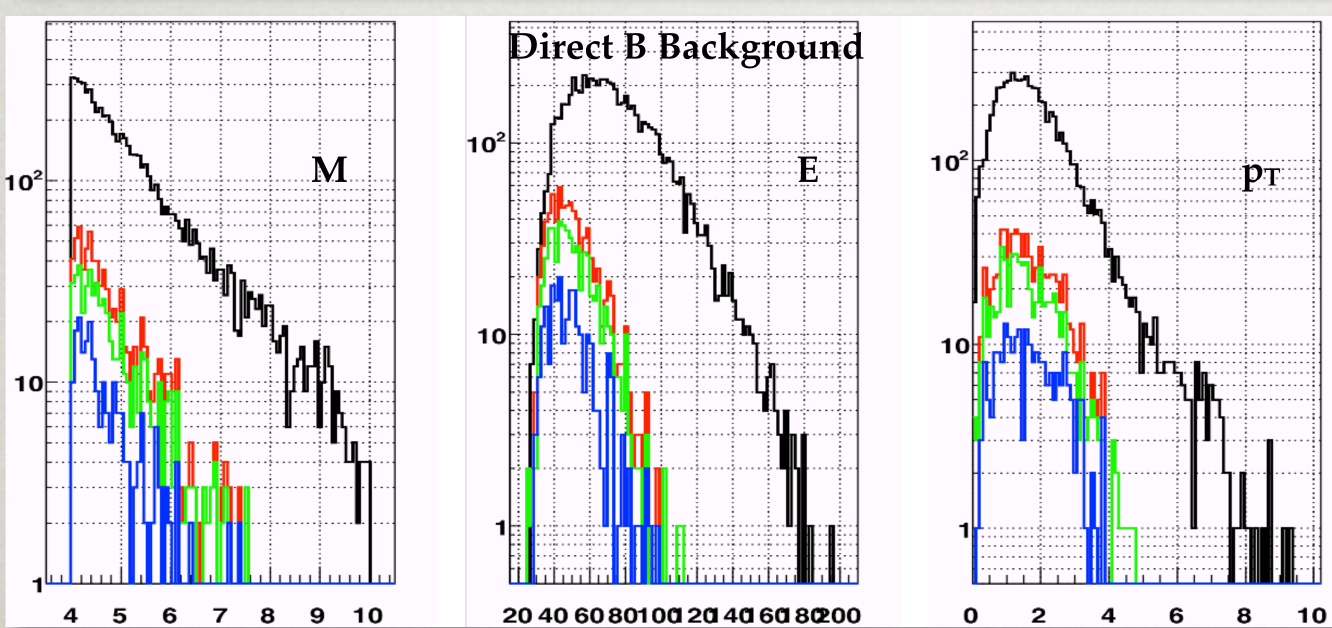
Forward Drell-Yan

The forward Drell-Yan measurement can reach $x < 10^{-3}$.
Initial simulation work has been performed based on FMS +HCal configuration.

Total DY
FMS Closed
FMS Open + HCal



DY Signal
Direct B
Unlike sign
Like sign



small at high x_F & high η & mostly unlike sign

pythia v6.222
p+p @ $\sqrt{s}$ = 500 GeV
DY: 4M evts @ 6.7E-05mb ~ 60/pb
e^+/e^- E > 10 GeV
p_T > 2 GeV, x_F > 0.1 (25 GeV)
4 GeV < M < 10 GeV

Required upgrades

Preshower for e/h and e/ϒ separation, conversion $e^+ e^-$ suppression.

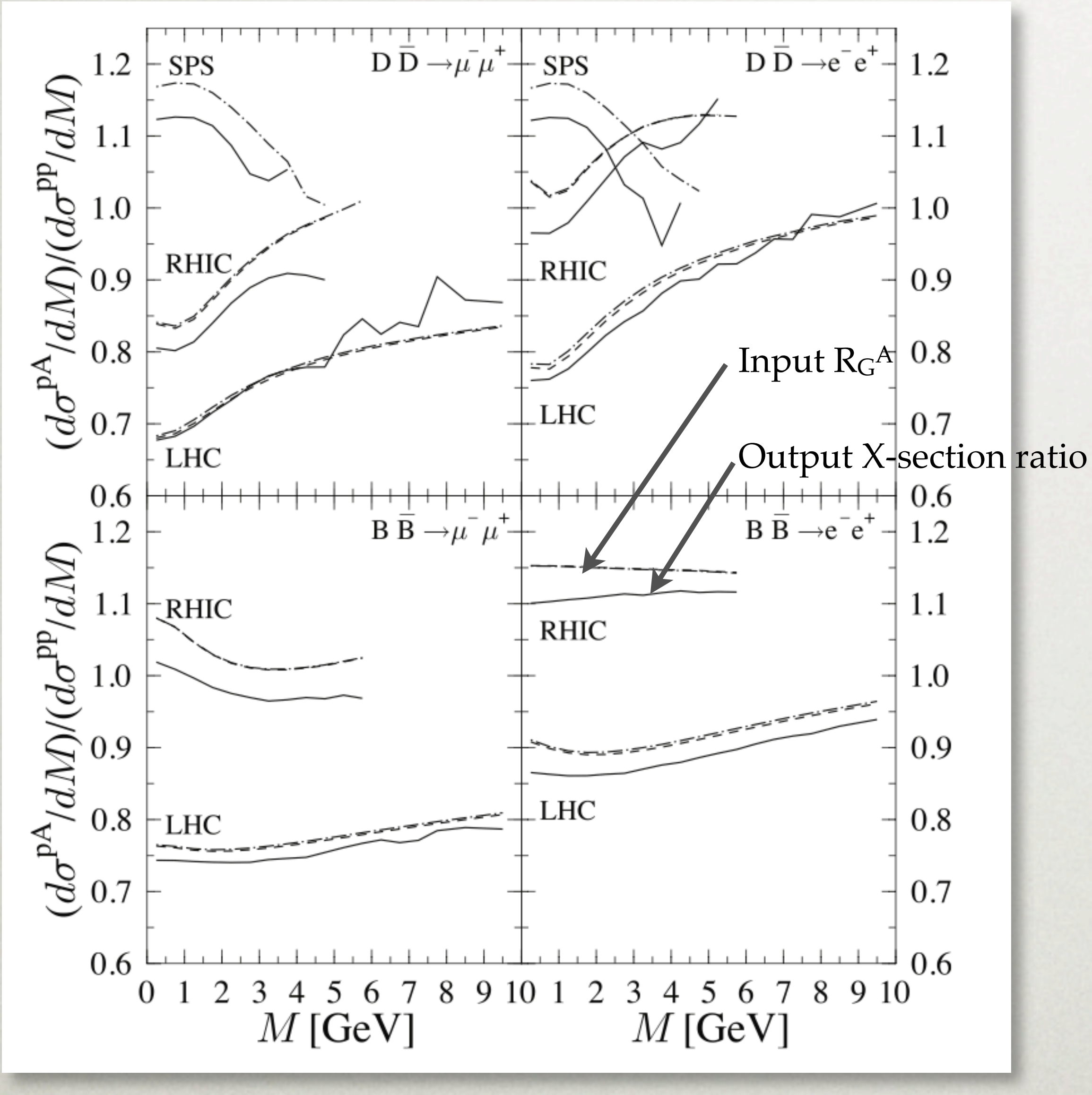
Extended high η coverage

Charge sign separation may be necessary → Tracking

Trigger upgrade for neutral veto

Correlated Charms

The ratio of correlated Charm pair cross-section, which is dominated by g-g fusion, between pA and pp is sensitive to the ratio $R_G^A = f_G^A / f_G^P$.
→ Access to the gluon nPDF at low-x



K.J. Eskola, V.J. Kolhinen, R. Vogt, Nucl.Phys. A696 (2001) 729-746

Theory calculation shows that pA/pp cross-section ratio tracks the input R_G^A very closely at RHIC energy.

Extending this measurement to the forward region would extend the x reach down to 10^{-3}, but requires substantial upgrades to catch correlated $e^+ e^-$ pairs.
→ Charge sign, e^-/Υ separation, PID?

p+p Forward Physics

Beyond collinear, leading twist factorization in pQCD

The origin of large A_N in hadron interactions still not fully understood.

→ A_N vs. p_T to understand the kinematic dependence of SSA.

→ Direct photon and inclusive jet A_N, sensitive only to Sivers effect.

→ Ultimately, Drell Yan A_N to verify sign change vs. SIDIS

Spin structure of the proton: quark transversity

The Collins and Interference Fragmentation Functions couple to quark transversity.

Unbroken universality: Can be connected directly to SIDIS and e^+e^- measurements.

→ Expand Mid-rapidity Collins and IFF measurements to the forward region.

Spin structure of the proton: sea quark polarization

The Λ hyperon spin transfer (D_{LL}) can probe the strange quark polarization.

→ Expand mid-rapidity Λ hyperon D_{LL} to the forward region.

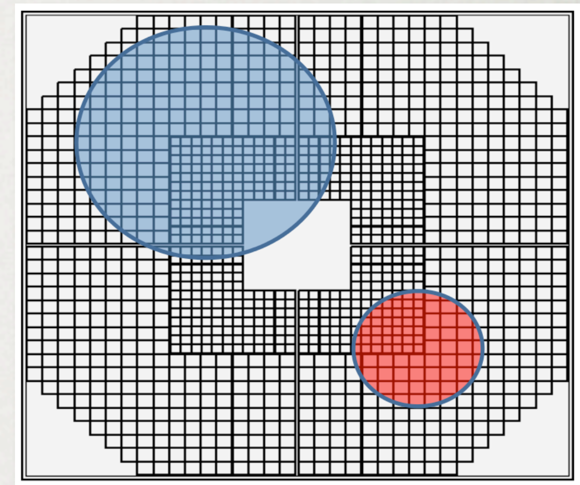
Diffractive physics through Roman Pot Phase II

Diffractive A_N: Single Pomeron Exchange, hadronic spin flip amplitude → published

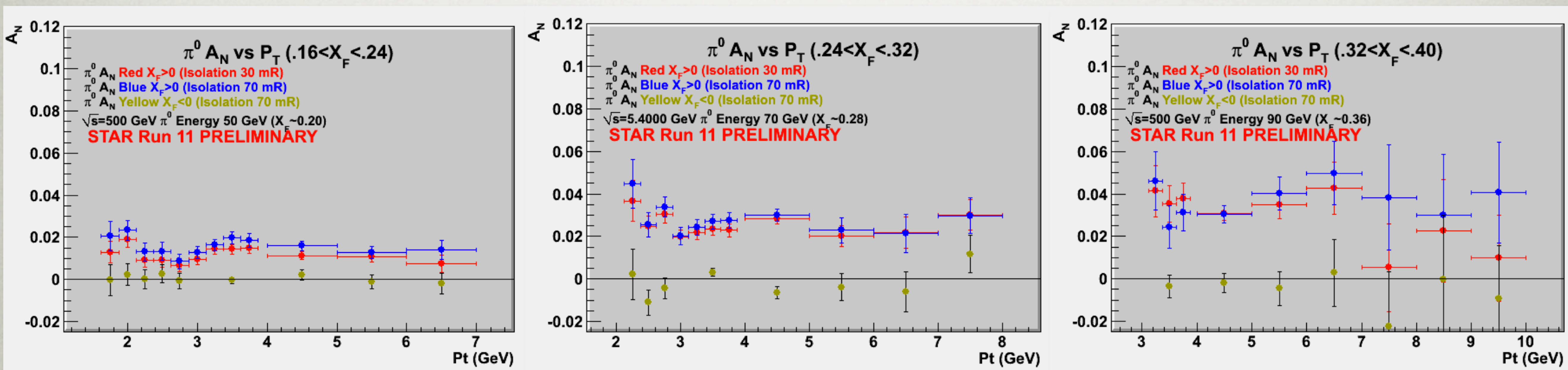
Central production: Double Pomeron Exchange, search for Glueballs

A_{UT} for exclusive J/Ψ in UPC in $p^{\uparrow}p$, $p^{\uparrow}A$: GPD E_g, requires proton tagging

Understanding A_N in p+p



1. The p_T dependence of A_N has been found to be **surprisingly flat out to pT ~ 10 GeV**
2. When we compare A_N vs. p_T for the two isolation cones at 30 and 70 mRad, we find that **the larger isolation cone produces consistently larger asymmetries**.



It is unclear whether existing theoretical models based on TMD or twist-3 effects can accommodate these features. More checks are needed.

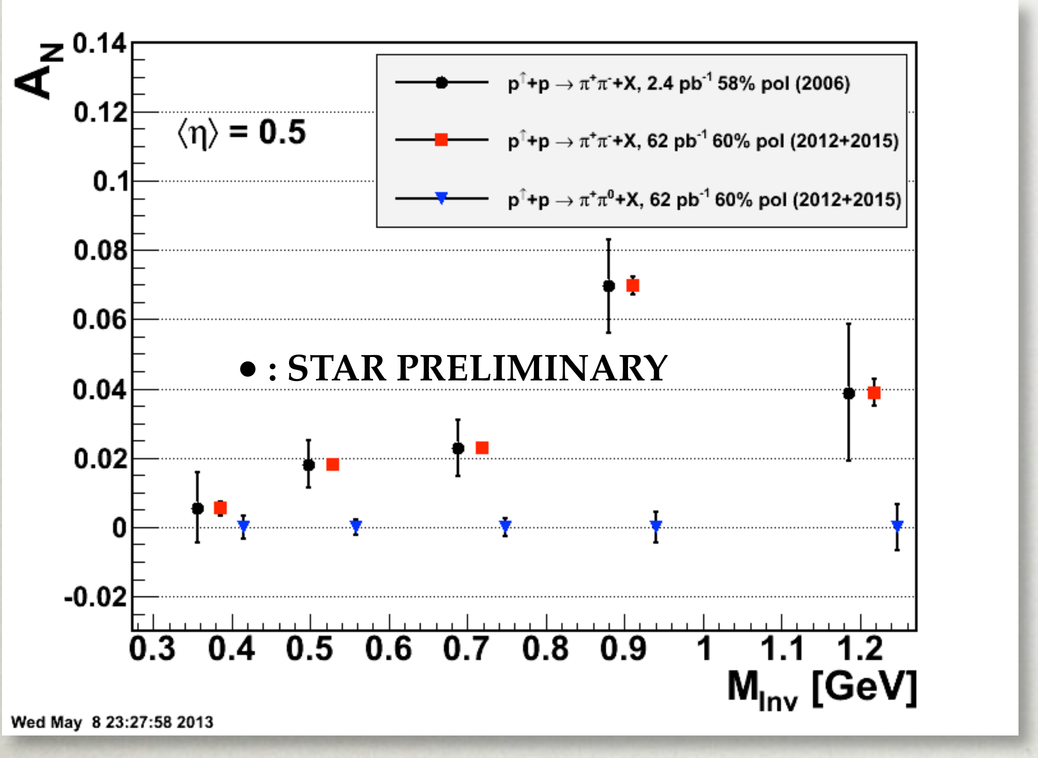
A_N for "cleaner" final states: Direct photons, inclusive jets, Drell-Yan

Correlation / event topology: Mid-rapidity detectors, forward charged tracks

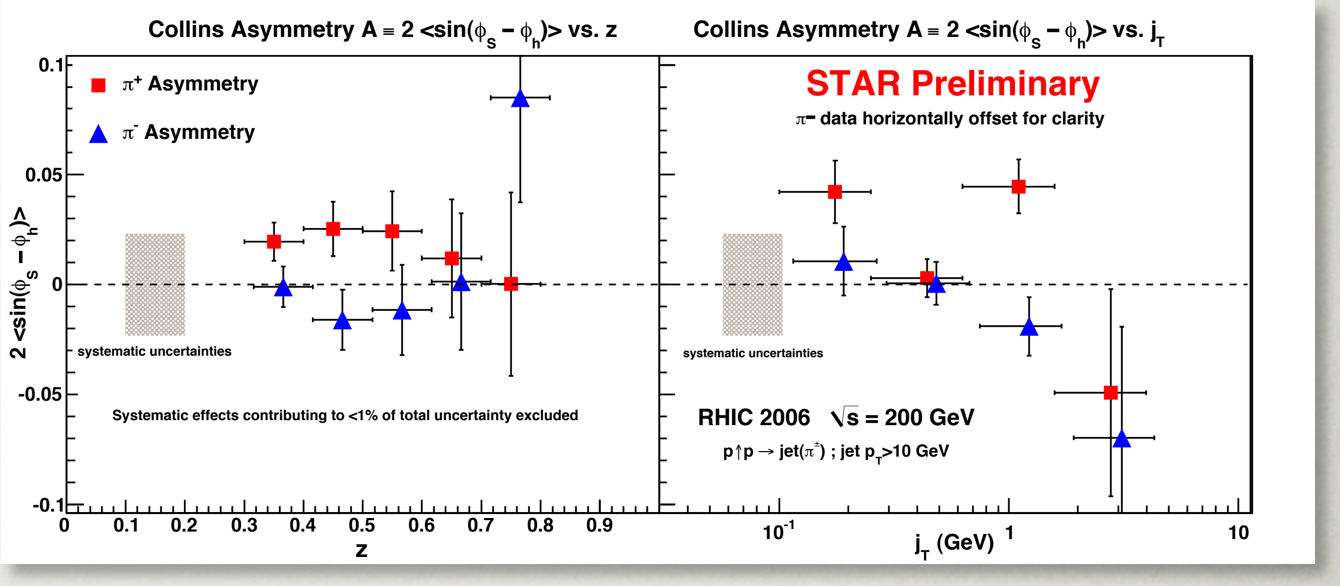
Quark Transversity

Expand the mid-rapidity Collins and IFF measurements to the forward region, which requires charge separated hadron capability.

Mid-rapidity IFF results and projection



Mid-rapidity Collins results



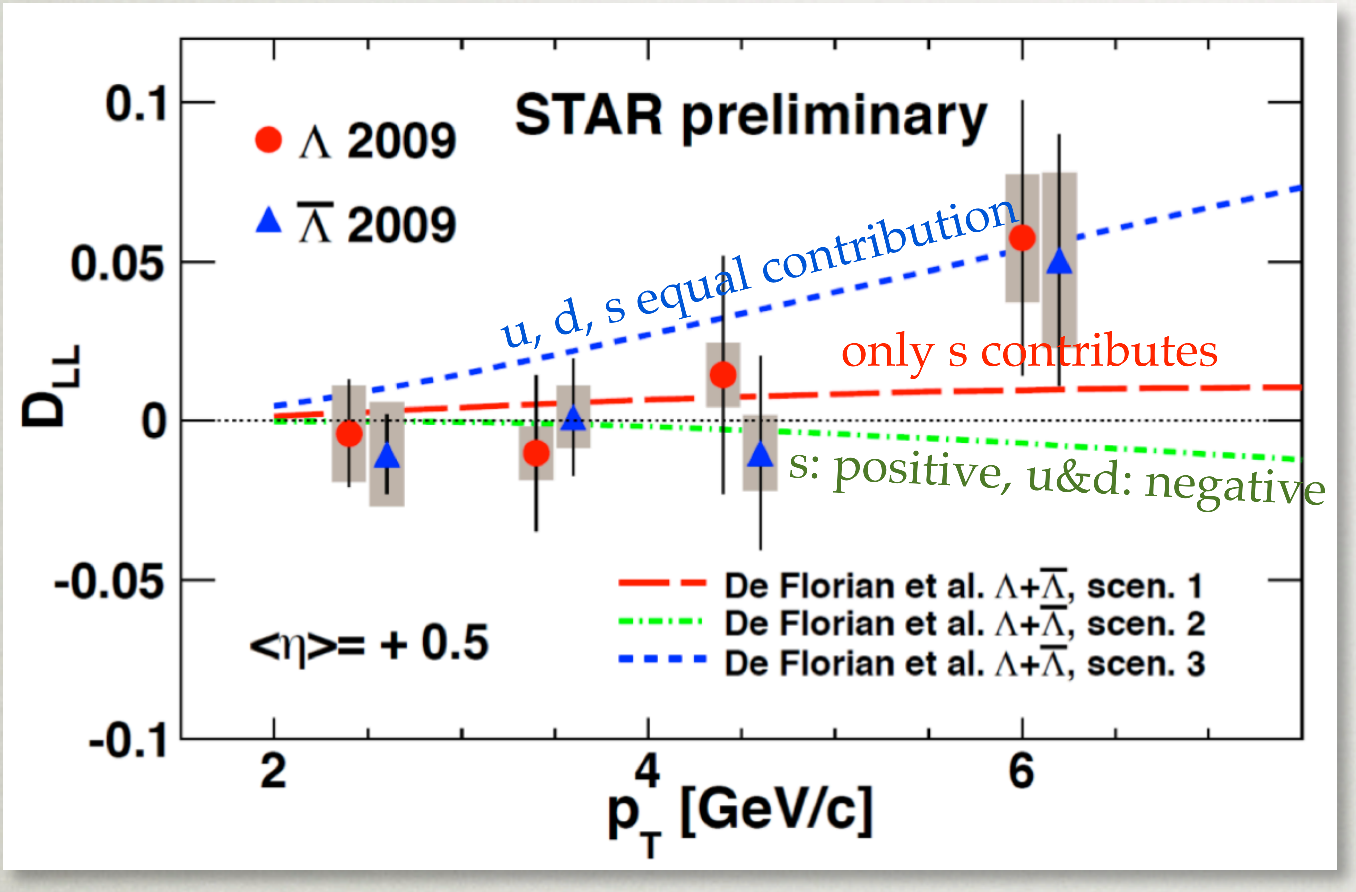
24 pb^{-1} of 200 GeV data were recorded in 2012, with P~60%. Analysis is on-going.

The forward measurements will extend the x_F reach to the higher x_F region, complementing the SIDIS extraction of transversity. (Anselmino et. al., arXiv:0812.4366 [hep-ph]).

Sea Quark Polarization

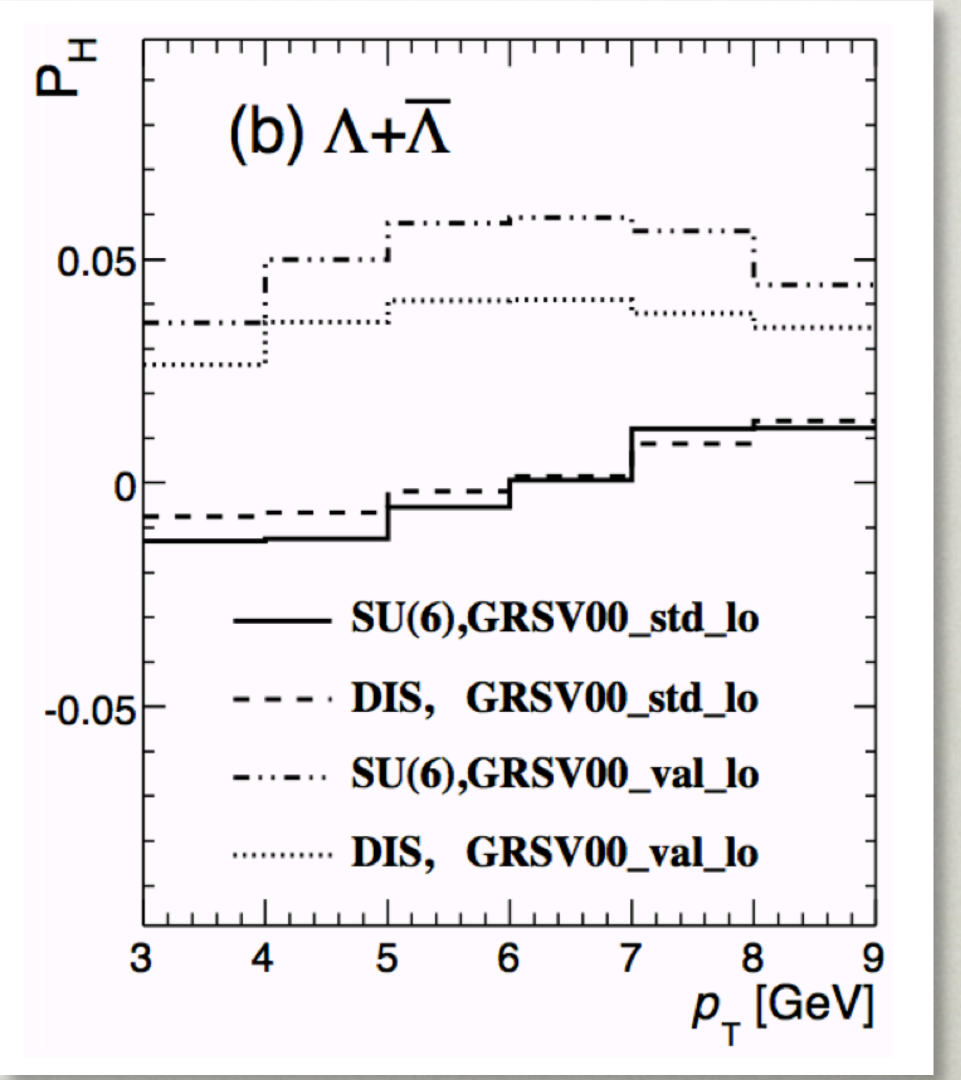
Λ-hyperon D_{LL} is sensitive to strange sea quark polarization.
→ Expand the mid-rapidity Λ D_{LL} measurement to the forward rapidity, either through $\Lambda \rightarrow n + \pi^0$, or $\Lambda \rightarrow p + \pi^-$ channels.

Mid-rapidity D_{LL}, $\sqrt{s}$ = 200 GeV



The expected size of the D_{LL} in the forward region is comparable to that in mid-rapidity.

Forward D_{LL}, $\sqrt{s}$ = 500 GeV, **2.5 < η < 3.5**

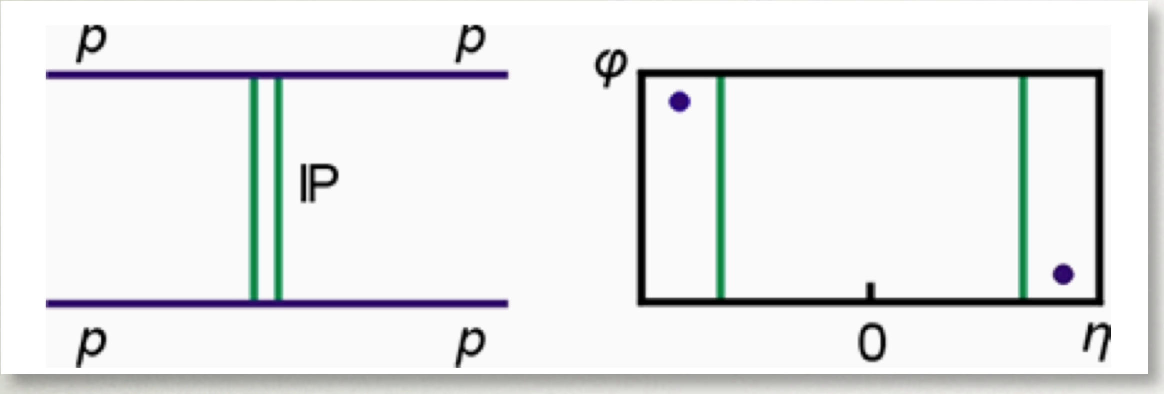


W. Zhou, S.-S. Zhou, and Q.-H. Xu, Phys. Rev. D81 (2010), 057501.

Diffractive Physics

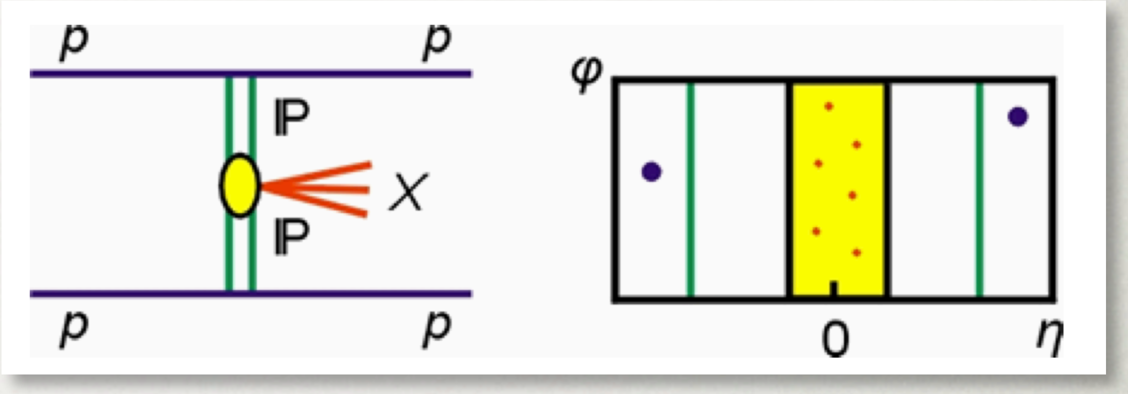
Intact protons on both sides of the beam, measured by Roman Pots.

Single Pomeron Exchange

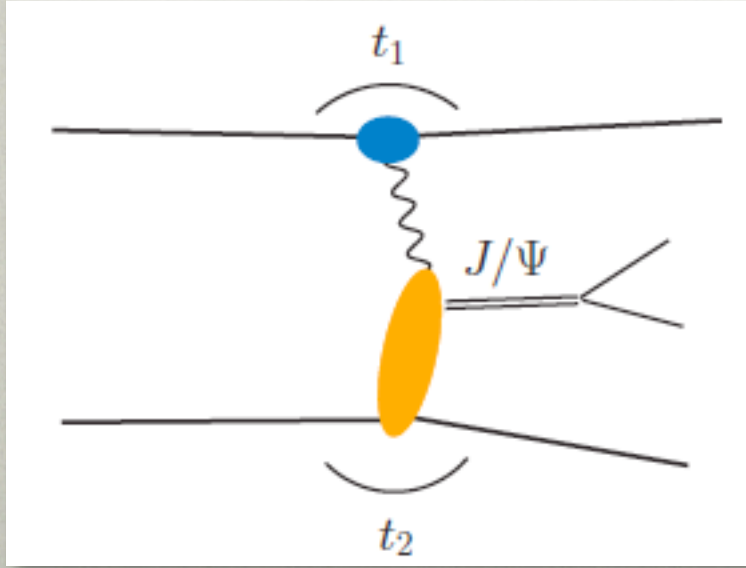


The |t|-dependence of elastic A_N probes contribution from **hadronic spin flip amplitude**. At RHIC energy, is was found to be consistent with zero. (Phys. Lett. B 719 (2013) 62)

Double Pomeron Exchange



Central production: Two Pomerons interact → M_X (1~3 GeV) in the central region. Pomerons: color singlet → two gluon bound states in QCD.
→ **Search for Glueballs**



Exclusive J/ψ A_{UT} in UPC

Pick very small t_1 → Quasi-real ϒ*, large impact parameter
Final state lepton pair → Time-like Compton scattering
Lepton pairs from J/ψ instead of ϒ* + Transversely polarized target → Helicity flip distribution E for Gluons.

Berkeley Lab

Detector Requirements

Inclusive Jets = EMCal + HCal

Collins, IFF = EMCal + HCal + Tracking ? PID
charge sign

$\Lambda \rightarrow p + \pi^-$ = HCal + Tracking ? PID
displaced vertex
charge sign?

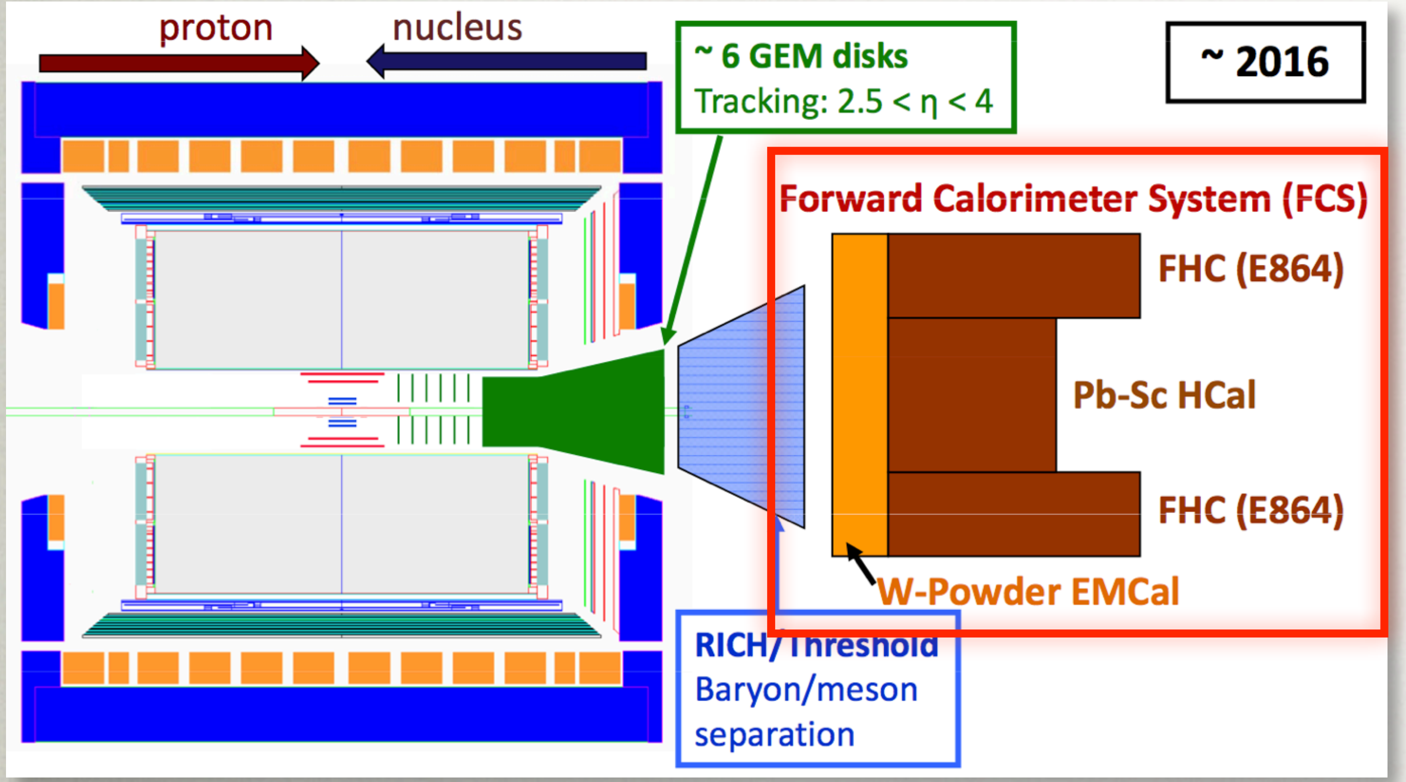
$\Lambda \rightarrow n + \pi^0$ = EMCal + HCal + Preshower
Neutron ID

Direct Photon = EMCal +{ HCal / Preshower }
hadron rejection / electron and hadron rejection

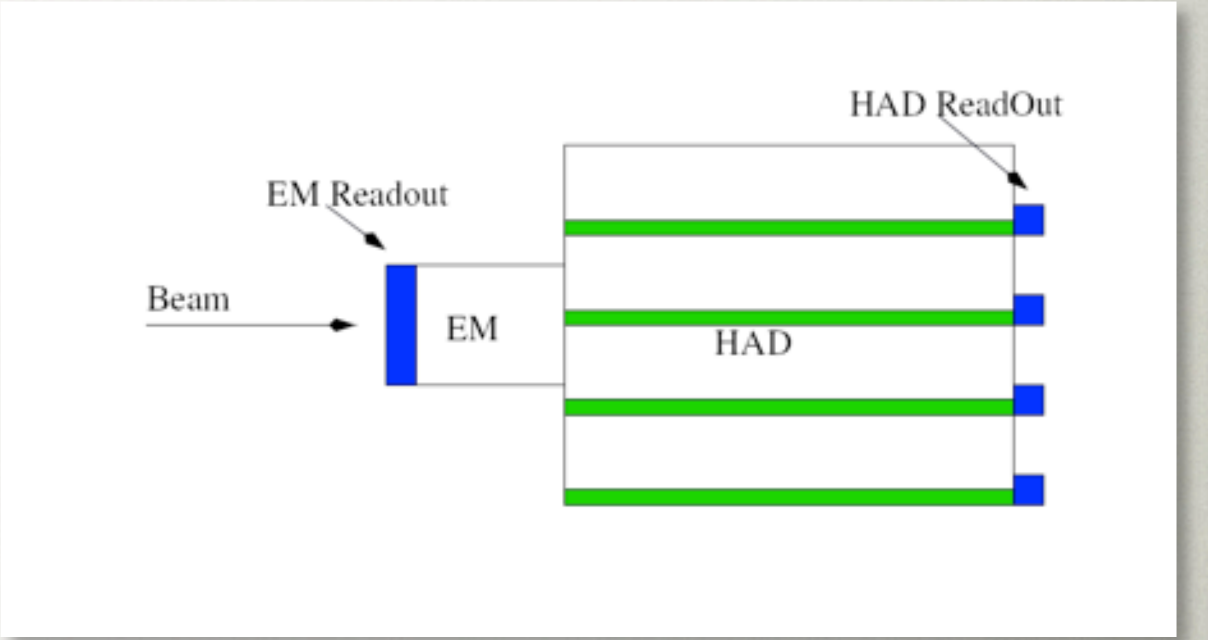
$e^+ e^-$ = EMCal + Preshower + Tracking + HCal
photon and hadron rejection / charge sign? / hadron rejection?

Charged hadrons = HCal + Tracking ? PID
charge sign
low p momentum?

Forward Calorimeter System



Prototype (~late 2013)

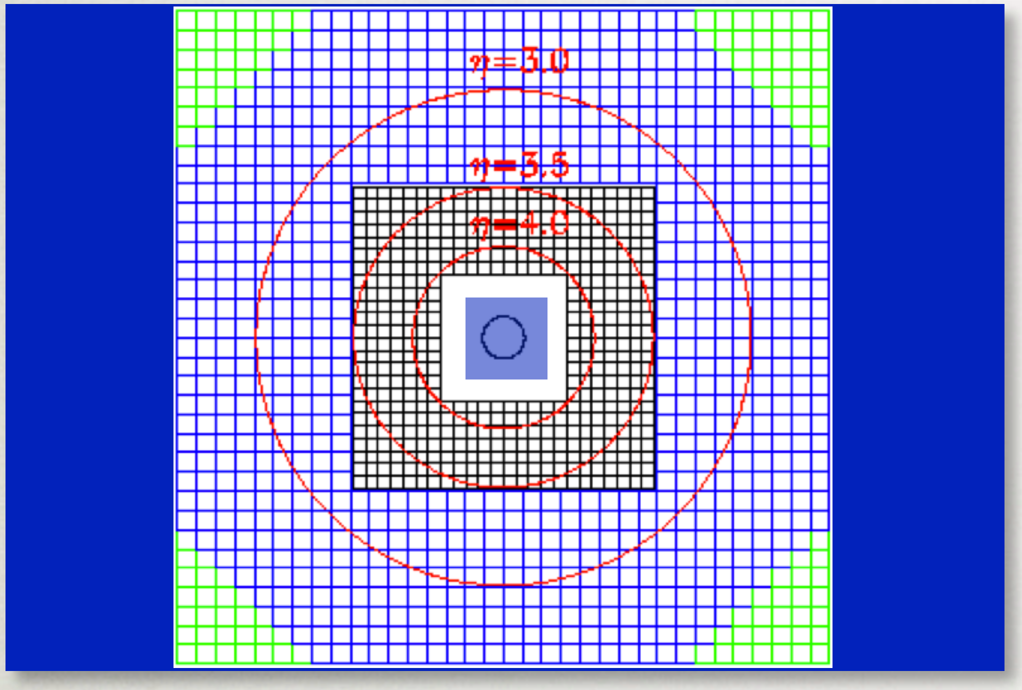


The Forward Calorimeter System (FCS) would replace the FMS, and add HCal.
Consists of 9600 (120x80) channel EM section and 600 (30x20) channel HCal section.
EMCal: new construction using W-powder / ScFi technology.
HCal: a hybrid of new construction (absorber-scintillator sandwich) and recycled units from previous experiments (E864, PHOBOS, AnDY).

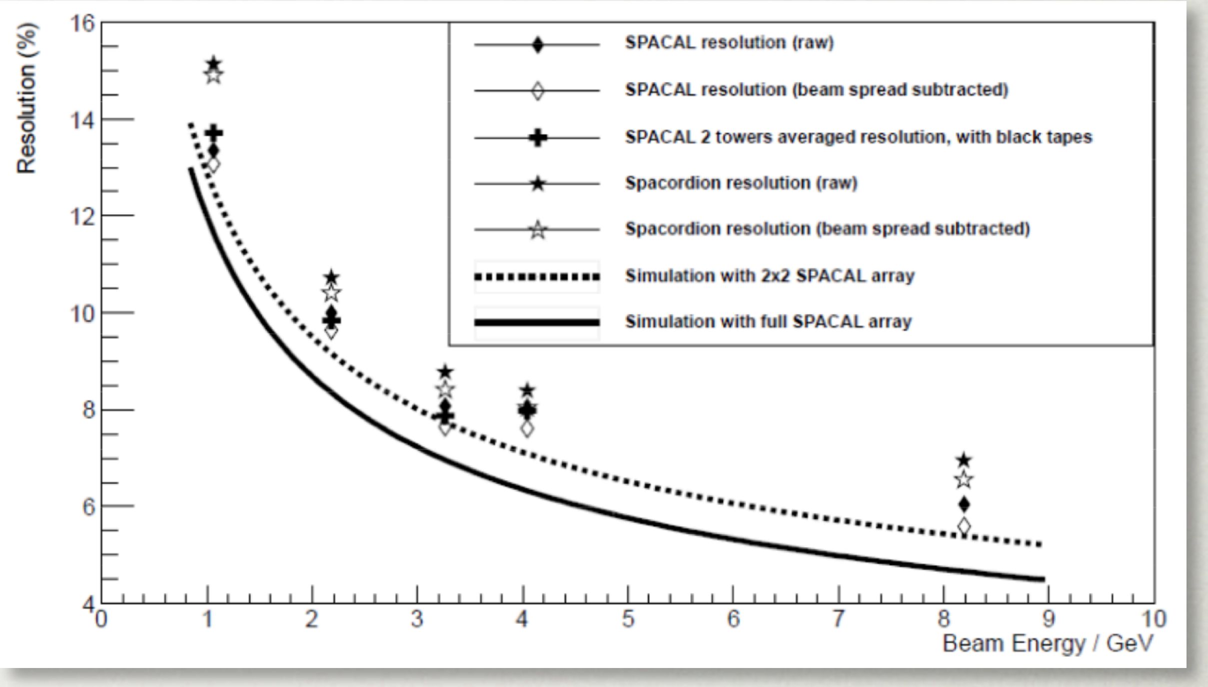
Construction of the prototype (4x4 EM section + HCal) is scheduled for this year.

FCS vs. FMS

FMS vs. FCS

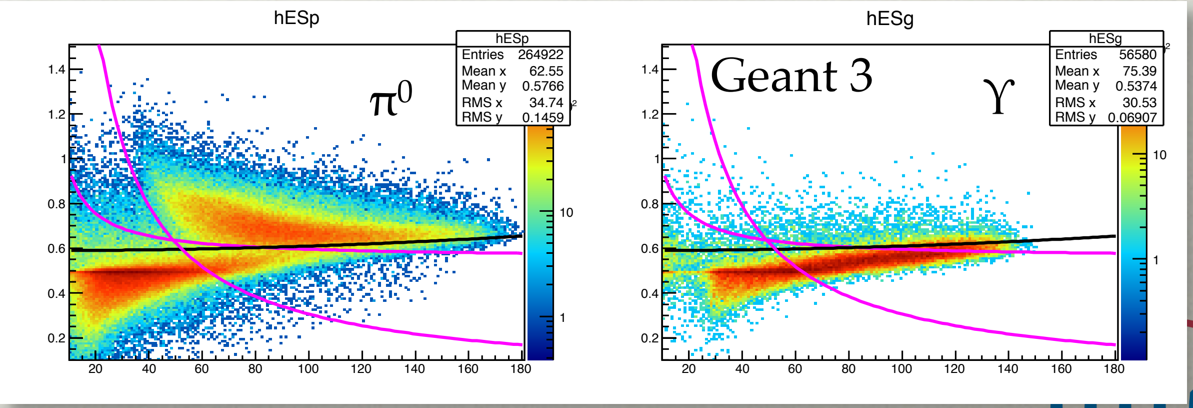


FCS EMCal E-resolution from FNAL test run



Pseudo-rapidity coverage: **From 2.2 (L/R) or 2.6 (T/B) to ~4.2.**
The granularity of the EMCal improves from **3.8 / 5.8 cm** of the FMS to **2.6 cm**.
The energy resolution improves from **~15% at 30 GeV** of the FMS to **~12%/√GeV + 2%**
The size of the beam hole is also reduced: **Crucial for Drell-Yan measurement.**

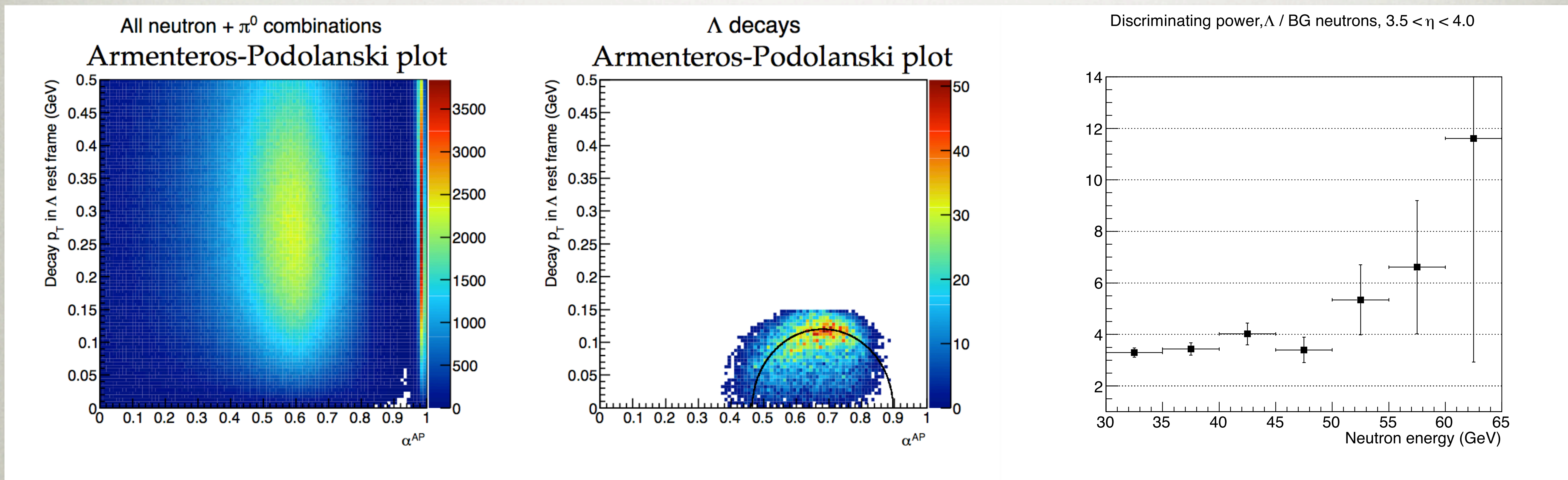
The limit of reliable **π^0 - Υ separation improves from ~80 GeV to ~120 GeV**, and may improve further with more optimized analysis techniques.



Cluster energy (GeV)

$\Lambda \rightarrow n + \pi^0$ with FCS

STAR is investigating the possibility of reconstructing Λ through its neutral decay channel using FCS + neutron ID (likely preshower).



FCS HCal energy resolution: 50%~60% / √GeV for 10~80 GeV

However, Pythia shows significant amount of random neutron and π^0 background dominating the event sample at 200 GeV.

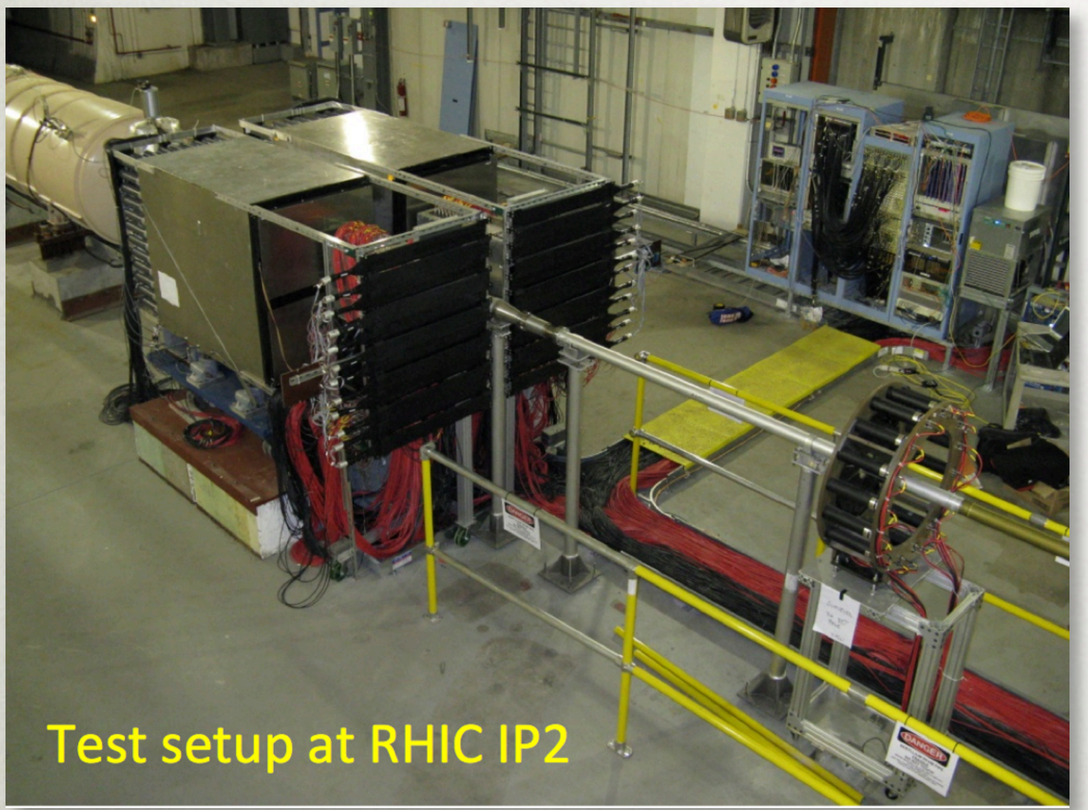
Displaced vertex cut is likely a must:

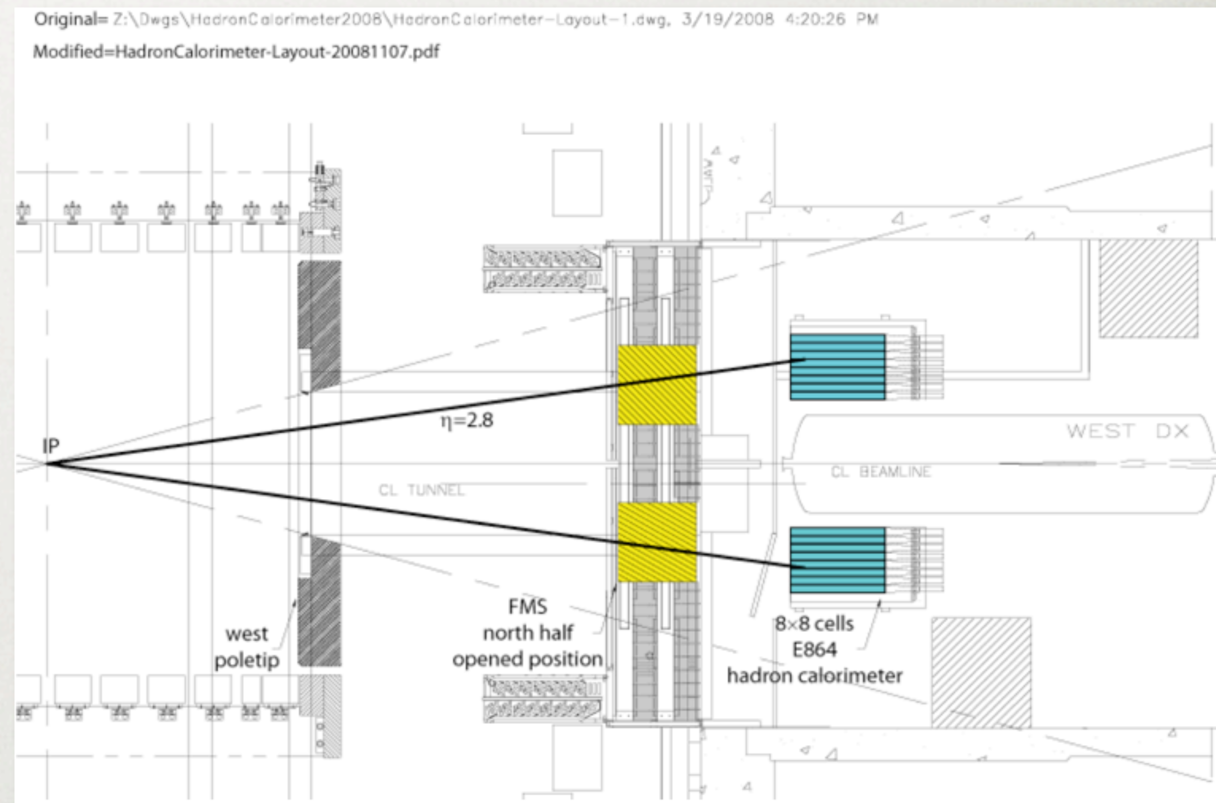
π^0 opening angle (mass) in $n+\pi^0$ channel → difficult

Charged particle tracking in $p+\pi^-$ channel → more promising

FMS + FHC

Alternatively, we could add HCal modules from E864 behind the FMS (open position). The HCal modules were recently used by AnDY.

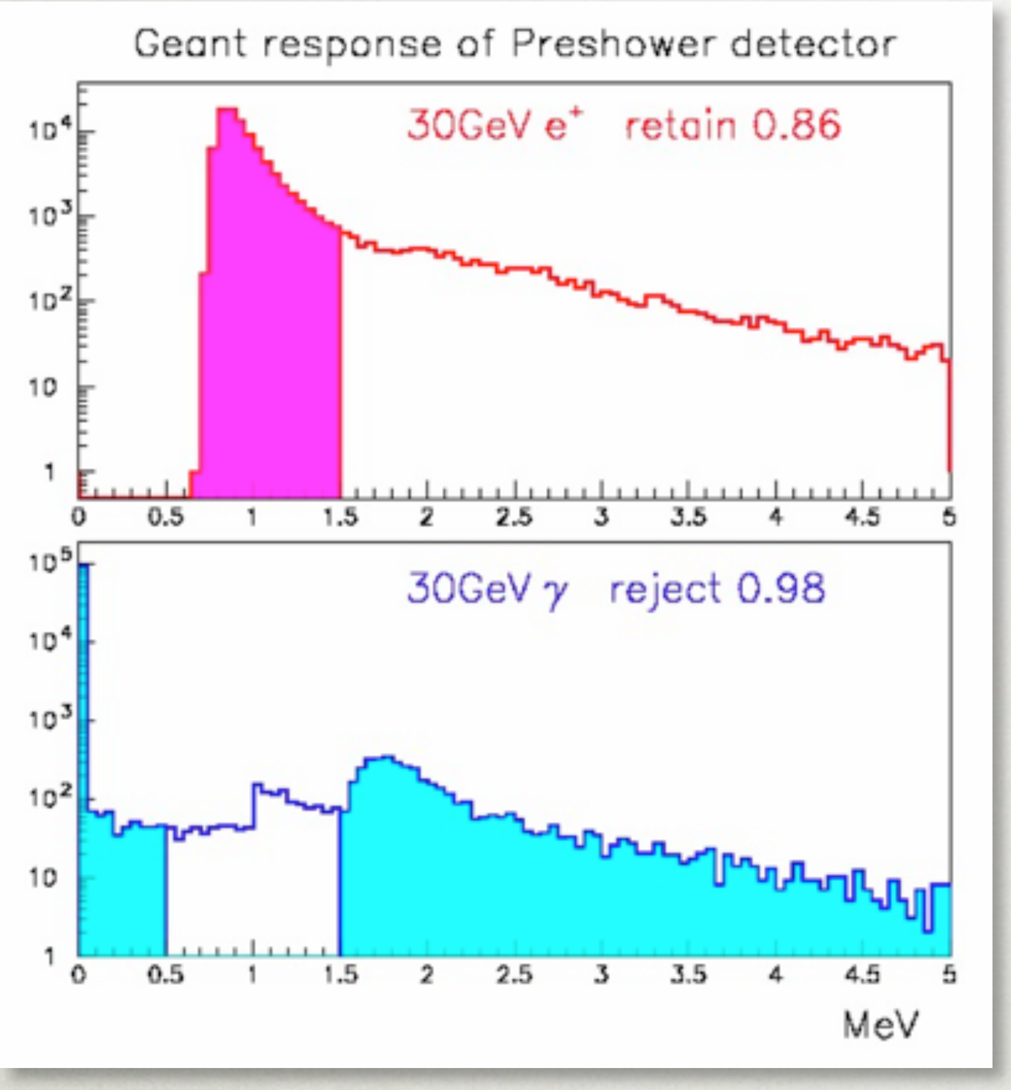


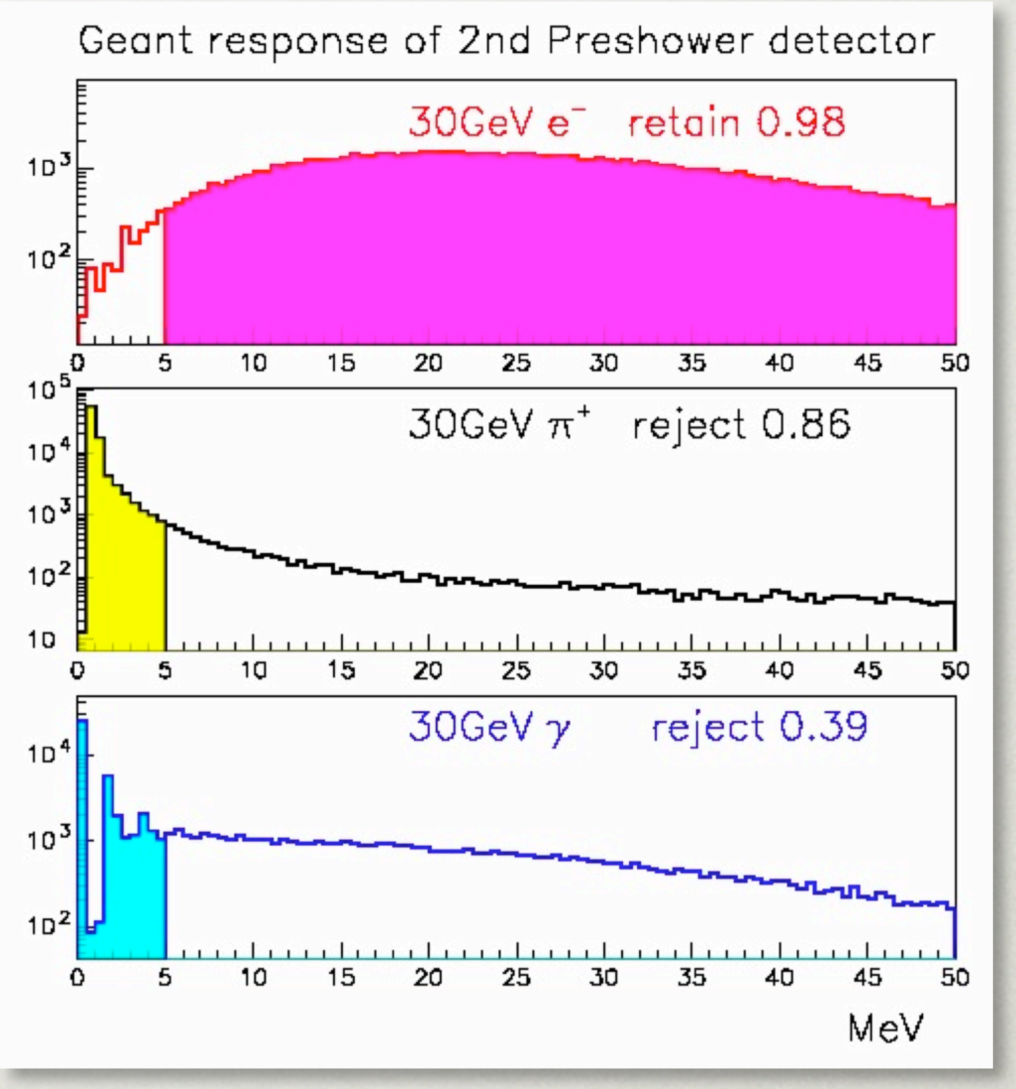


Consists of 10 cm × 10 cm × 120 cm cells of SPACAL.
Detector performance well understood from its recent use.
Expected to make up a portion of the FCS HCal section.
Cannot cover the FMS in closed position, not very forward ($\eta < 3$).

FMS Pre-shower

Preshower for the FMS will enable separation of e, ϒ, and charged hadrons.
It could also provide large-Z space points for the forward tracking.

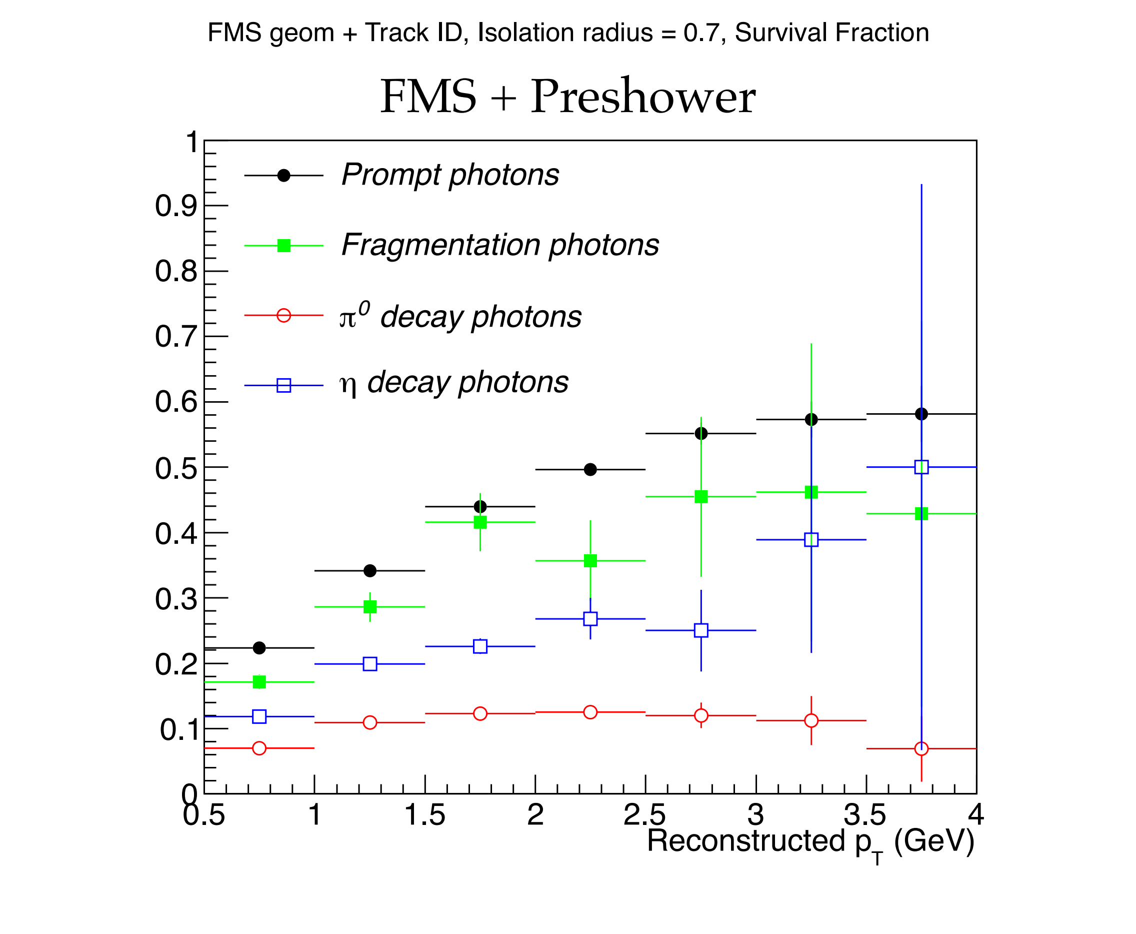


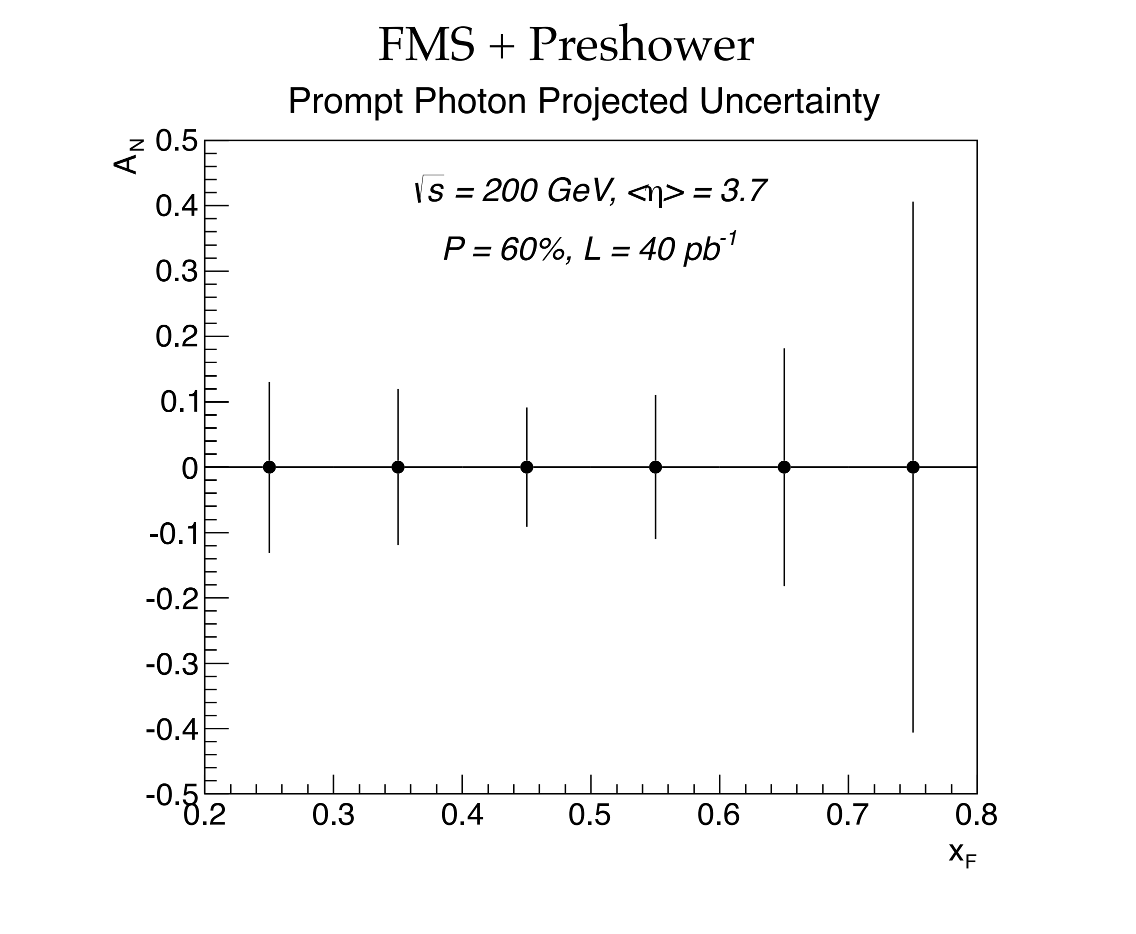


The design consists of two 0.5 cm scintillator plates and 1 cm Pb convertor in-between.
First layer: Reject 98% of ϒ, retain 86% of e^-
Second layer: Reject 86% of π^+ and 39% of ϒ, retain 98% of e^-

FMS Pre-shower

In addition to its use for electron ID, preshower can also serve as charged particle veto for the direct photon measurement.



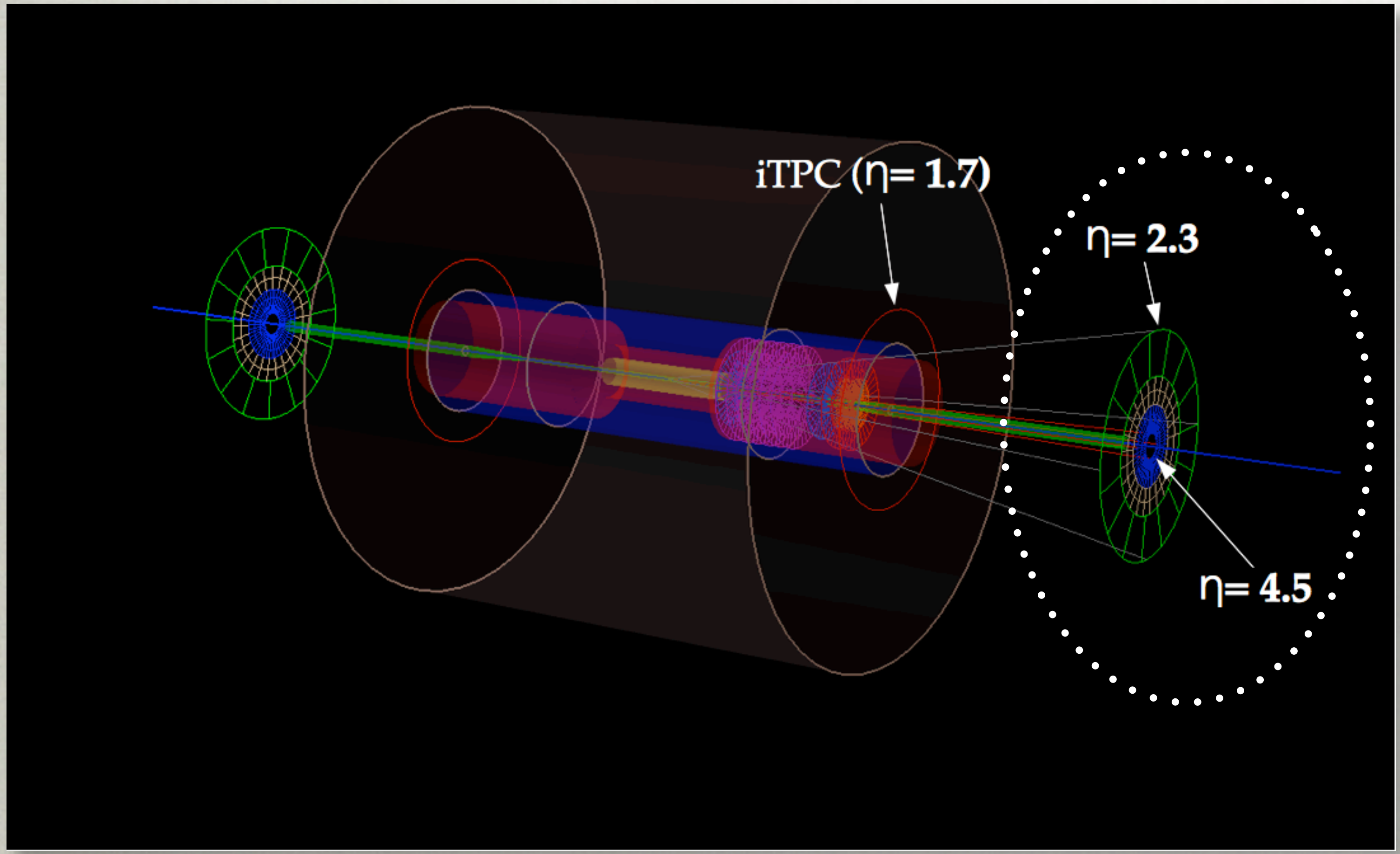


The current estimate of the uncertainty for the prompt photon A_N, assuming 5% uncertainty in fragmentation photon A_N, for 40 pb^{-1} looks promising.
The sign of the prompt photon A_N is expected to provide crucial link between twist-3 and TMD formalisms.

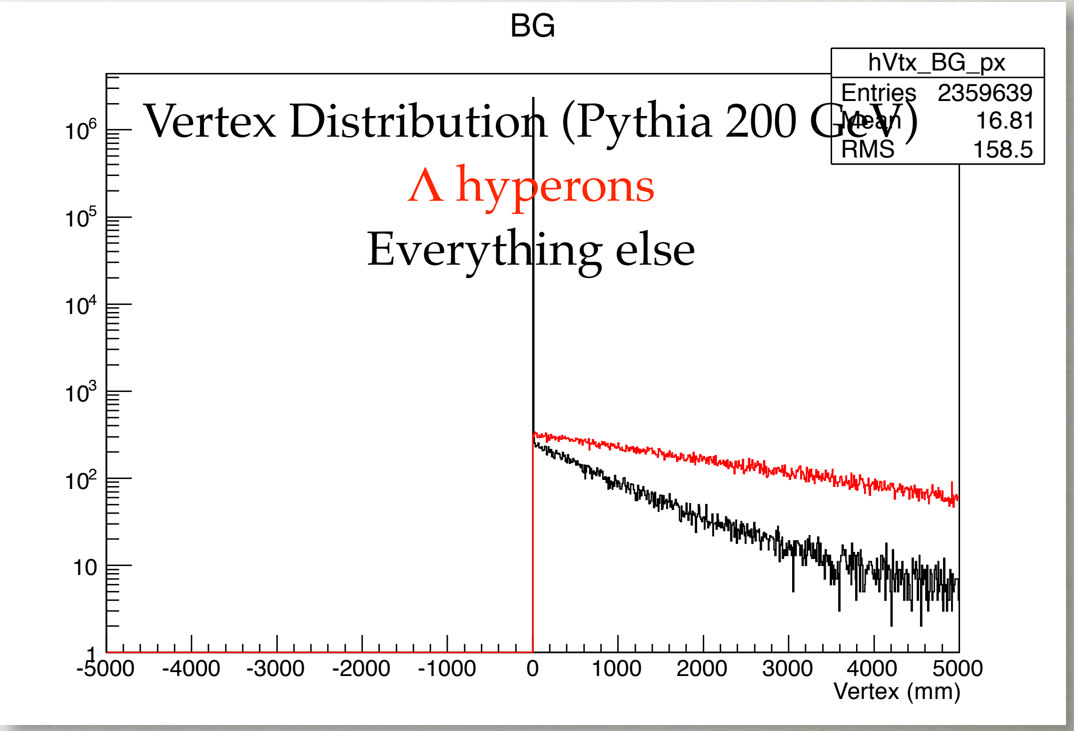
Displaced Vertex Finder

The minimum tracking requirement for Λ reconstruction is displaced vertex measurement for $\Lambda \rightarrow p + \pi^-$ channel.

The simplest possibility is to combine the proposed event plane detector (HALO) with the calorimeter preshower to do two point tracking.



HALO's primary purpose is for event plane reconstruction during BES II



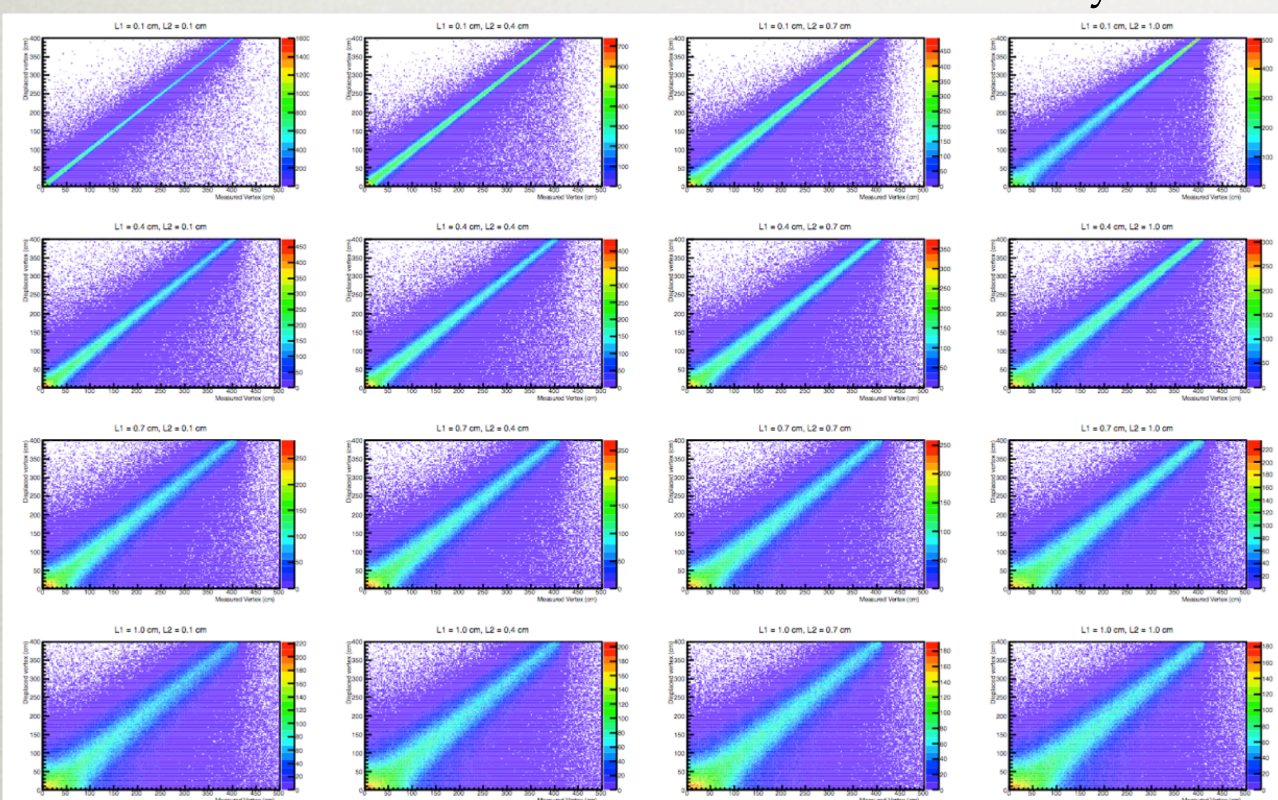
Vertex cut at ~1m rejects most of the BG while retaining ~70% of Λ's.
→ Resolution requirement is low,

Displaced Vertex Finder

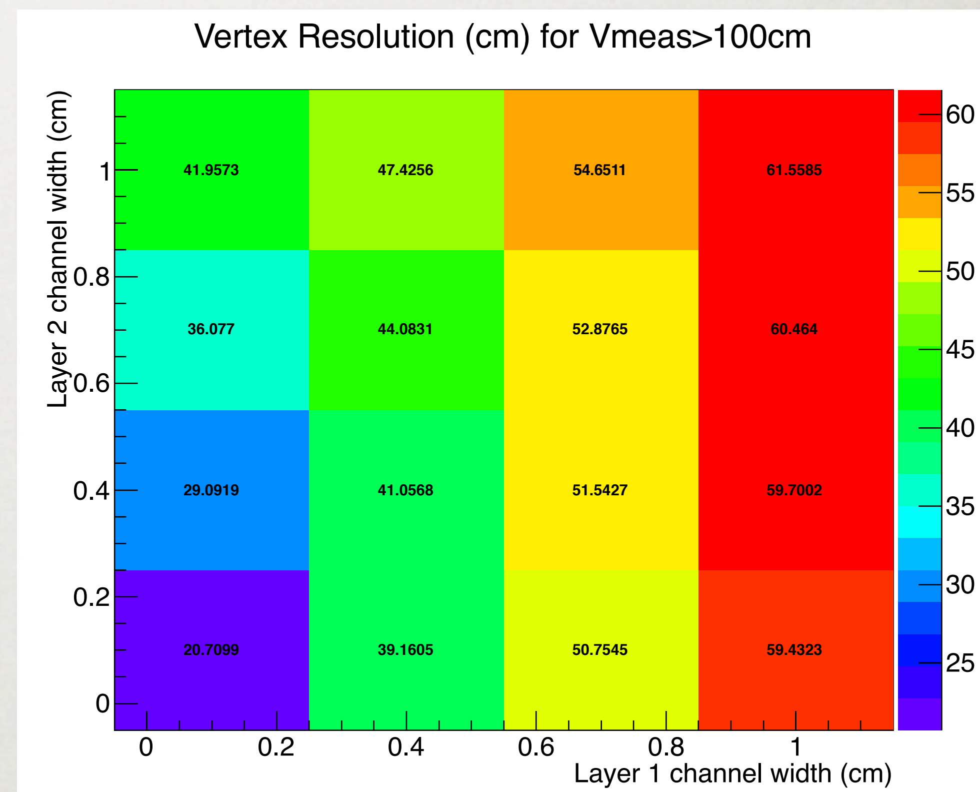
For p+p, multiplicity is too low in this region to cause track matching ambiguity. Resolution primarily depends on the pitch size for the two planes.

Toy-MC scan of pitch size in layer 1 &2 from 1 mm to 10 mm

True vertex vs. measured vertex for Λ decays



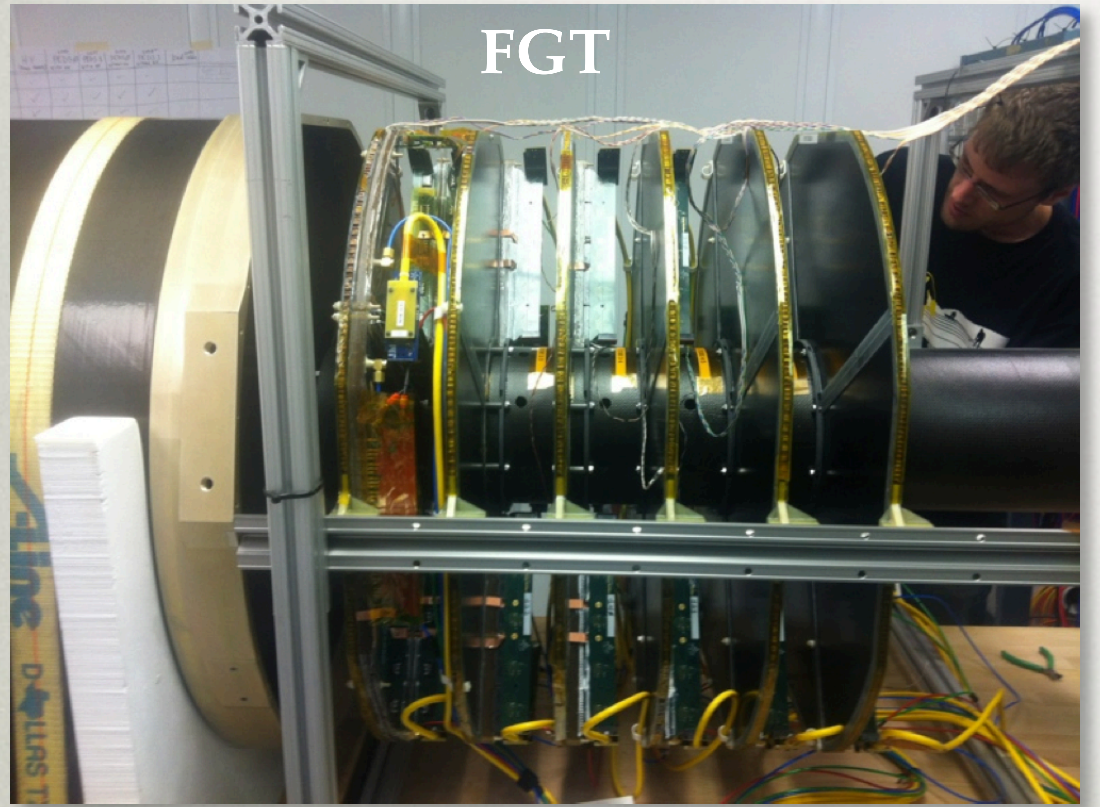
Vertex resolution in cm

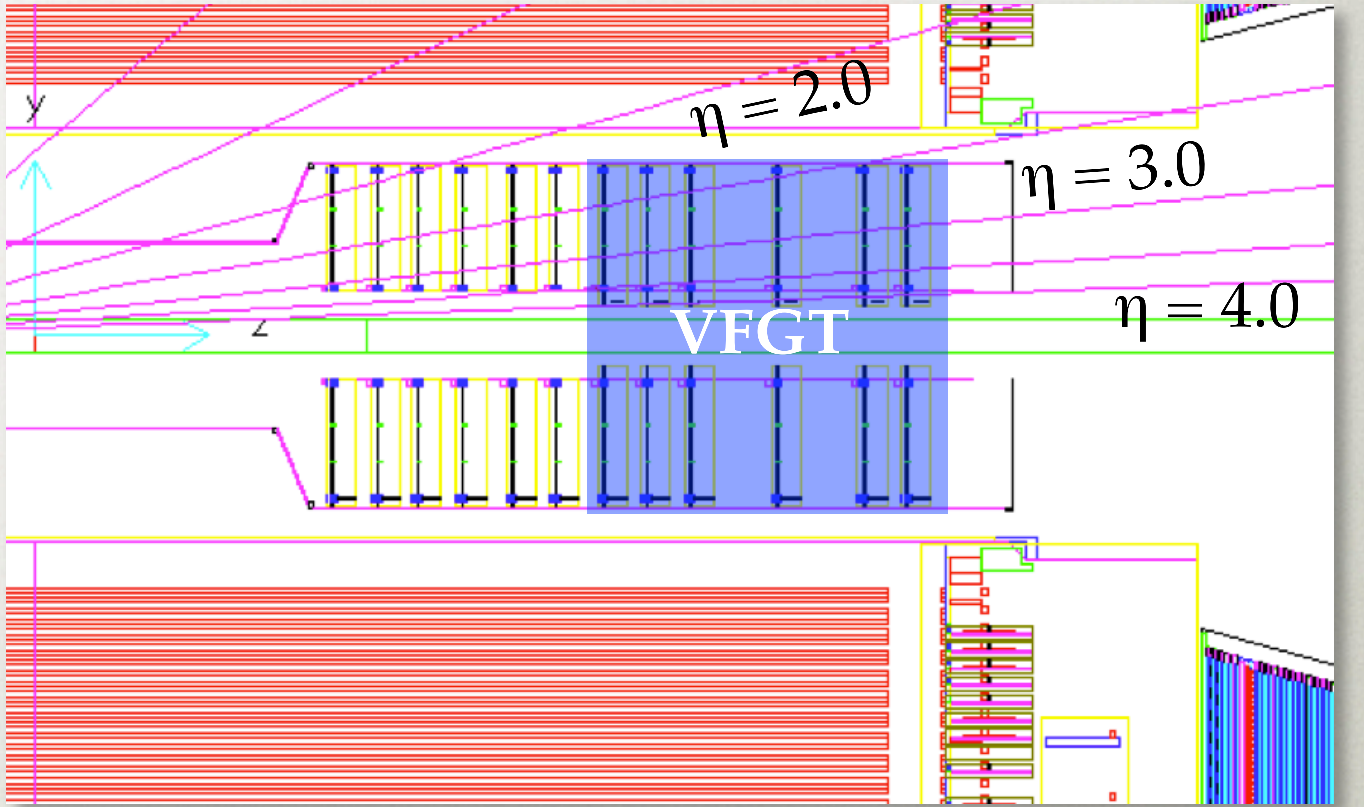


The vertex resolution is generally poor (~ 40 cm) with ~mm pitch sizes, but this may still be good enough to identify Λ decays with a large vertex cut.

Tracking Option 1 - VFGT

Many of the proposed measurements require forward tracking with charge sign capability. One possibility is to extend the existing Forward GEM Tracker to cover more forward region: Known technology, good spatial resolution. (< 100 μm)

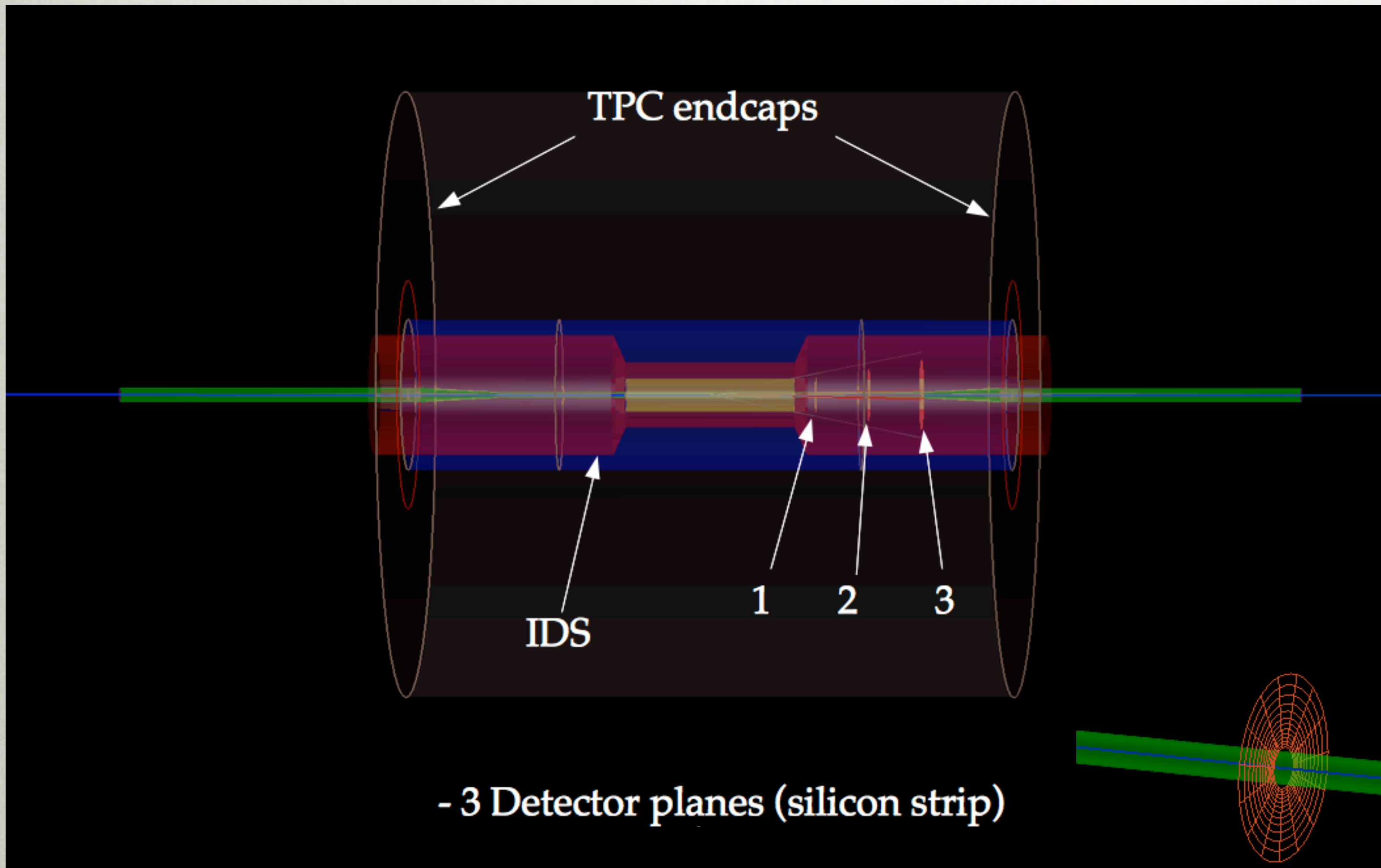




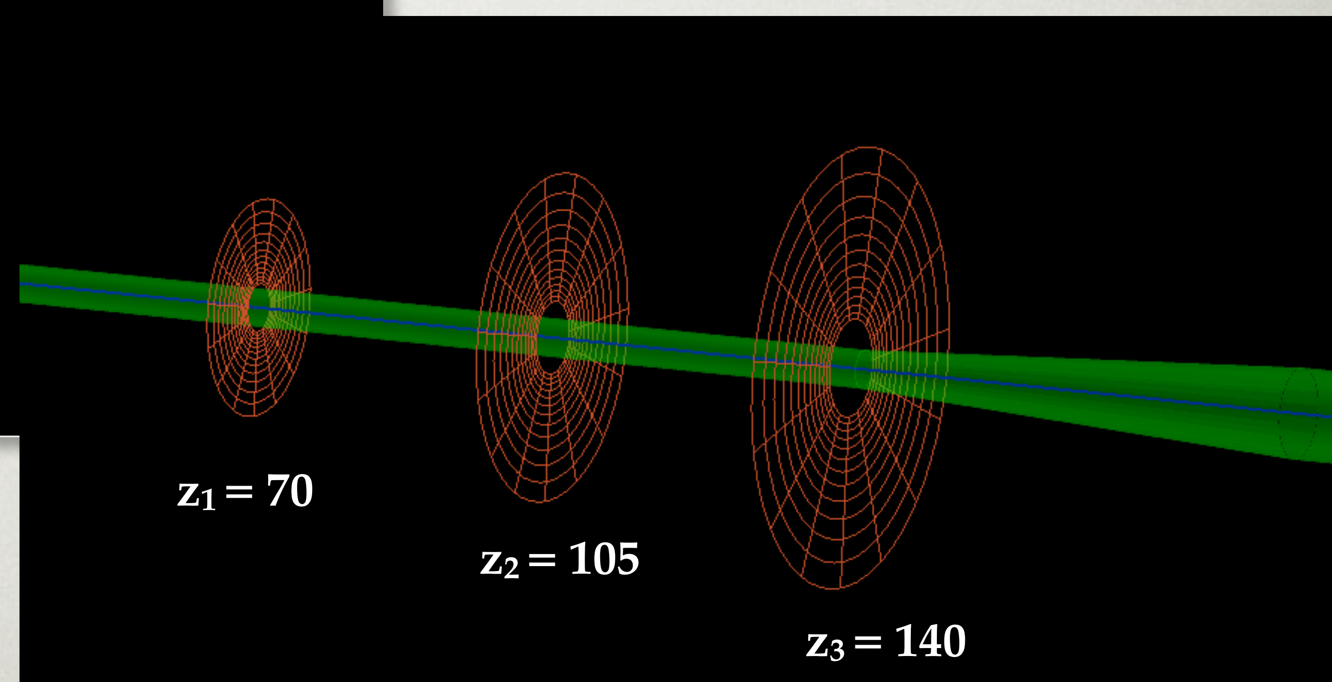
Requires 6 additional GEM disks with inner radius of 7 cm.
η coverage up to 4.0 with shifted primary vertex ($z = -50$ cm), $\eta < 3.5$ with $z = 0$ cm.
Designed specifically for 500 GeV W measurement.
More study needed to understand capability as a general purpose tracker.

Tracking Option 2 - SI Strips

Alternatively, a new tracker concept based on 3 layers of silicon strip planes are being considered.



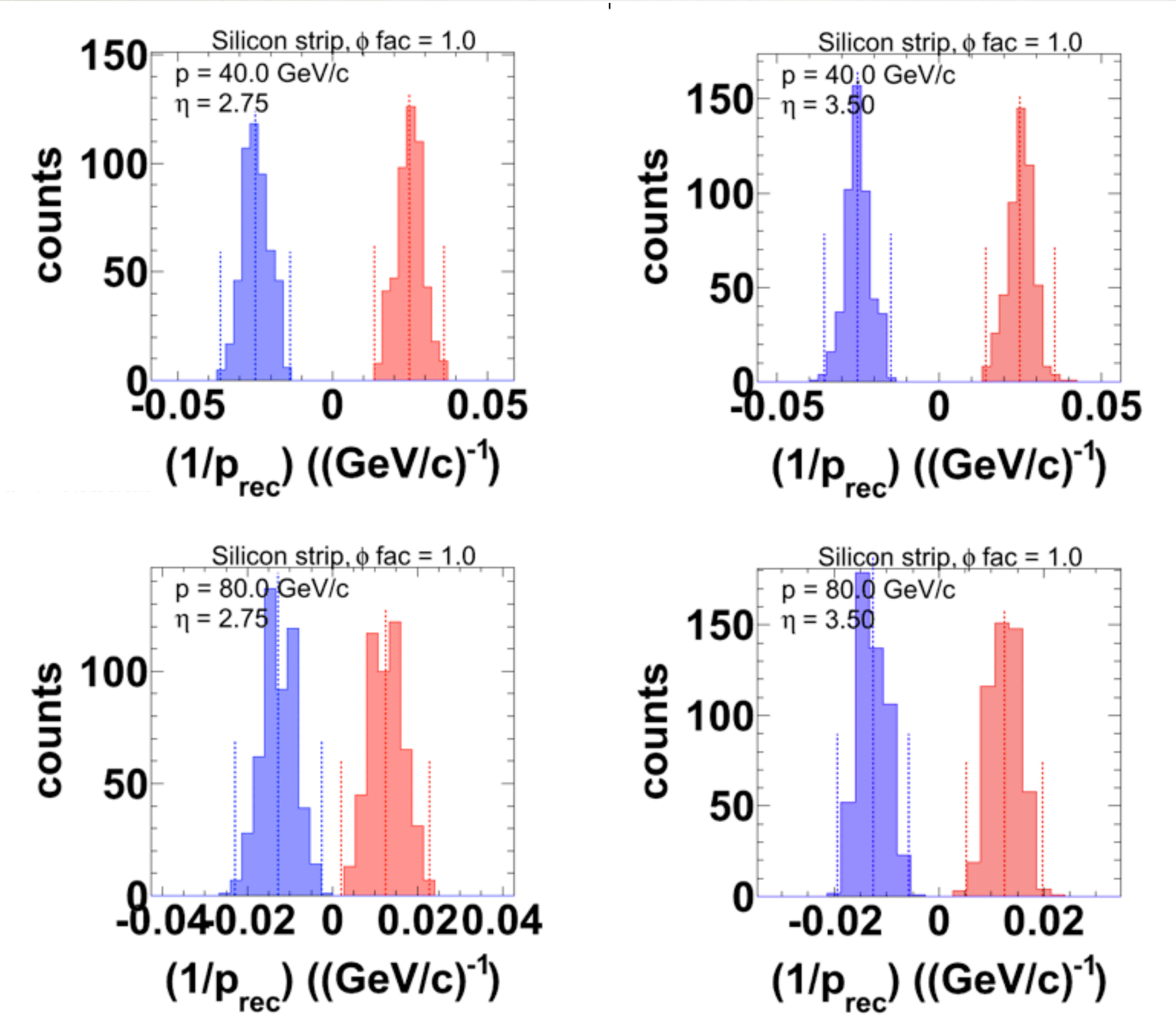
This setup will provide moderate momentum resolution for low momentum (~ few GeV) tracks. **Charge sign separation is expected to be robust up to ~80 GeV of track energy.**



Pitch size varies from layer to layer and as a function of η.

R: 4 mm ~ 3 cm, Φ: 0.1 ~ 0.8 mm

Tracking Option 2 - SI Strips



ϕ fac:
- pitch factor in azimuthal direction

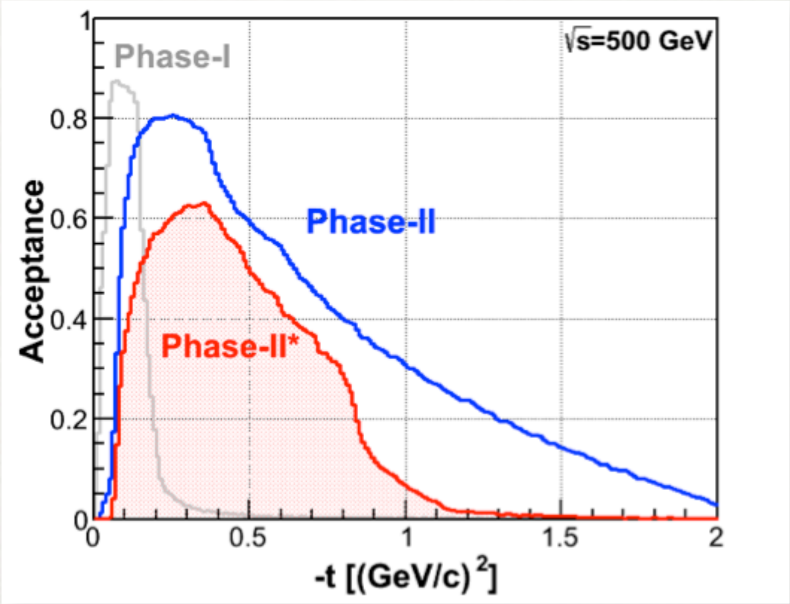
X0:
- 1.2% radiation length per plane
- + 0.2 cm Be
- + rest air

Primary vertex:
- only x-y coordinates used
- "pitch": 200 μm

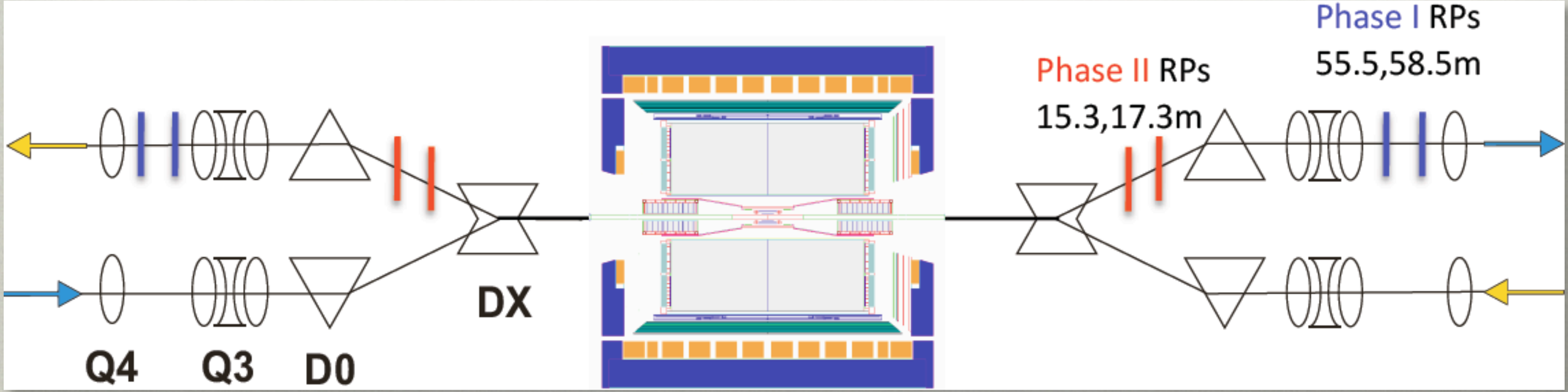
The pitch size as a function of η is currently being optimized.

Roman Pot Phase II

Roman Pots measure forward scattered protons in diffractive processes



Phase I (Installed): for low-t coverage
Phase II (planned) : for higher-t coverage, new RPs, reinstall old ones at old place
Phase II* (planned) : for higher-t coverage, re-use RP from Phase I



Dedicated runs (special beam optics) no longer necessary
→ Concurrent measurement at mid-rapidity: GPD E_g, Glueball search

Summary

STAR Decadal plan calls for upgrades to the forward region, including **improved calorimetry with HCal, forward tracking, and PID**. These upgrades are essential for many of the physics topics in the upcoming $p^{\uparrow} + A$ and $p^{\uparrow} + p^{\uparrow}$ collisions.

The construction of a prototype for the **Forward Calorimeter System (FCS)** is moving forward: Improved EMCal performance + overlapping HCal coverage.

A scintillator based concept for the **FMS preshower** detector, which is essential in leptonic channels and direct photon measurements, is being considered.

STAR is evaluating two alternative technologies for the forward tracking.

1. An extension of the existing FGT detector into **VFGT**
2. A new concept using three layers of **SI strip detectors**.

Roman Pot Phase II will provide a dramatically improved acceptance relative to phase I, and will eliminate the need for special beam optics.

Exciting time for forward physics!